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GEOPHYSICAL INSTITUTE

of the

UNIVERSITY OF ALASKA

Final Report

TECTONIC MOVEMENT, DEFORMATION RELEASE AND CRUSTAL STRUCTURE STUDIES IN ALASKA

by

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AFOSR Contract F 44620-68-C-0066

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PERSONNEL

The program of intergrated research described in these pages could not have been possible without the interest dedication, and professional competence of every member of the seismological laboratory. The principal investigator wishes to express his thanks to all and looks forward to the achievements that the continuing cooperation will bring.

Dr. Hans Pulpan, Assistant Professor

Larry Gedney, Assistant Geophysicist

John Davies, Senior Research Assistant

Niki Bloom, Research Assistant

Ronald Rasmussen, Engineer

William Feetham, Engineering Aide (left, April, 1969)

Orwin Westwick, Engineering Aide

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Linda Uhlman, Data Analyst

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We also express our sincere thanks to the NASA Gilmore station manager, Ed Eisele,, for the permission to operate and maintain the Gilmore borehole station, for the help he has given us, and for the data link he has allowed to be used.

Finally we would like to express appreciation for the close cooperation of the U.S.C.G.S. Palmer-Tsunami Warning Network and the College Observatory in providing records and other useful information for the present program.

ABSTRACT

This report covers the effort during the two year period 1968-69 supported by AFOSR. The main purpose of the contract was to gain a better insight in the seismicity, tectonics and the crustal failure mechanism in Alaska, provide data to different agencies and finally install borehole packages in a tripartite network.

The past two years have seen therefore a steady development in two areas. Through the telemeter system, the Seismic Laboratory of the University's Geophysical Institute has now on hand an almost complete record on the seismicity of Central Alaska, covering a total of three years and of much higher accuracy than was hitherto available. This information is not only vital to the many military installations, but increasingly so to the State of Alaska with its rapid economic development.

A good start has been made in understanding the tectonic processes, including the stress systems, which are active in producing the Alaskan earthquakes. This includes a close scrutiny of many aspects of the June 21, 1967, Fairbanks quake and its aftershocks. Through this contract three borehole packages have been obtained and included in the telemeter network at Paxson, McKinley, and Gilmore. This installation serves the research on the long period seismic spectrum above 20 sec for more stringently discriminating explosions from earthquakes in the low magnitude range and the earth tilts associated with tectonic activity and earthquakes. This will permit a better understanding of the crustal failure mechanism.

Tilts recorded so far have revealed an hitherto unknown pressure sensitivity of the long-period X component of the packages. Tilts associated with large earthquakes, correspond roughly with those recorded

elsewhere in the world at similar epicentral distances. However, this seems to be the first time in North America that tilts directly associated with source area deformation from small magnitude earth tremors have been obtained in the 15 km distance range. Tilts obtained only partially conform with the theoretical tilts obtained from dislocation theory.

Finally results obtained by other investigators in the laboratory on brittle rock failure seem to be valid for the earth crust. If foreshocks occur at all, their statistics, namely the "b" slope of the Gutenberg Richter Relation, linking the log of the number to the magnitude of earthquakes, seem to indicate high average stress levels [compared to the failure stress in unfracture rock] for small areas and prior to small main shocks, whereas larger areas associated with relatively stronger earthquakes seem to be associated with lower average stress levels.

In the following, published articles are given as abstracts only, other work is rendered in more detail.

LARGE APERTURE TELEMETERING SYSTEM FOR CENTRAL ALASKA

The system was planned in 1965. The first stations operated in the winter of 1966-67. During the period 1968-69 several stations have been added. These stations include the three borehole instruments located at Gilmore (GLM), Paxson (PAX), and McKinley (MCK). For details on the instrumentation of the borehole packages see a later chapter.

The geographical coordinates of the stations were selected so as to cover the regions of highest seismicity in the Alaskan interior, the area of active volcanoes adjacent to Cook Inlet (the oil fields), and the Alaskan Peninsula (Fig. 1). These volcanoes are potentially dangerous to vital civil and military operations in the State. The largest aperture of the system at present is 745 km (BIG-PJD). Its axis of highest resolution (perpendicular to BIG-PJD) is oriented 125° and 305°E of N (toward the Nevada test site). Experience has shown that earthquakes of body wave magnitudes of 4.0 in the 80° distance range can be detected by the routine reading of the Develocorder record, at least in favorable directions (Berg and others, July, 1967). The use of borehole seismometers has improved the signal-to-noise ratio for the short-period seismometers at a similar location such as PJD compared to GLM. There is a strong suggestion that the noise level at individual stations depends largely on the gross tectonic structure. S/N variation in the network is more than 5:1. In addition, the sensitivity depends on the direction of the wave approach with respect to these structures. It is suggested that the low wind areas of the geologically older formations of interior Alaska constitute ideal sites for a very high gain network. So far, seven short-period sites are in unattended operation with completely uniform equipment.

The equipment has been described by Berg and others (July, 1967). The short period seismometer/amplifier combination at the other three borehole sites is different. To date no equipment failure has occurred in the remote sites. Four of the stations have never been revisited since the installation.

UNIVERSITY OF ALASKA TELEMETER STATIONS

SP Vertical Only			
TNN	65° 15.4' N	151° 54.7' W	504m
BIG	59° 23.36'	155° 12.98'	562m
SVW	61° 06.9'	155° 35.9'	
SCM	61° 50.00'	147° 19.66'	1020m
PJD	65° 02.065'	147° 30.55'	740m
BLR	63° 30.10'	145° 50.72'	809m
MCB	64° 43.70'	147° 12.61'	213m
Bore Hole			
MCK	63° 44.02'	148° 55.95'	610m (ground surface)
PAX	62° 58.19'	145° 28.12'	1034m (ground surface)
GLM (prelim)	64° 59.24'	147° 23.34'	722m (ground surface)

The timing of the system has been improved by installing a primary time standard and Vela uniform time-code generator. This equipment was obtained with the borehole packages. It was found extremely useful to have second pulses directly on the Develocorder records.

TRANSMISSION OF P-WAVE DATA TO THE U.S.C. & G.S.

The arrival times of P-waves have been sent to the USC & GS Data Center in Washington, D.C., on a regular basis. Only those arrivals were sent which could clearly be recognized at least in three station.

EPICENTERS, SEISMICITY, AND STRAIN RELEASE, CENTRAL ALASKA

Monthly epicenter maps have been prepared since the operation of the telemeter system was started (first map, February, 1967). These maps have been continued through the present contract period. They include epicenters of quakes with local magnitudes from two upwards. Only quakes are included that are recorded clearly at three stations. The epicenter location computer program developed by Gedney and based on Herrin's 1968 tables (Herrin, 1968), uses first P-wave arrivals only (Fig. 2, A to W). Therefore locations outside the network are not so reliable. Locations show a systematic offset south of the line BIG-SCM. They also have a tendendy to drift outside the network, if located close to a station (such as near Fairbanks) or between stations (such as between TNN and PJD). This latter effect is obvious for the aftershocks of the October 31, Mag. 6½ Rampart earthquake. Their location is probably confined to the area south of the Yukon River (see epicenter maps from October, 1968, on).

Major areas of continued activity are the southwestern part of the Alaskan Range the Lake Clark Fault-Cook Inlet region and the immediate vicinity of the active volcanoes Jliamna and Redoubt, as well as the Prince William Sound. The Fairbanks area is continuously active (since the June 1967 quake) and many shocks in the magnitude range from 3 to 4½ have been felt. This NNW-SSE trending zone seems to have expanded. One magnitude 4 shock has occurred NNW of PJD and was associated with a tilt offset at GLM at an epicentral distance of 15 km (Berg, 1969).

The magnitude 6-½ to 6-$\frac{3}{4}$ shock near Rampart (at mid-distance between TNN and PJD, Fig. 1) on October 29, 1969, was one of the major shocks recorded during the contract period in the telemeter network. This shock occurred in hitherto quiet area and was followed by many aftershocks. It was strongly felt in Fairbanks some 130 km away. A short field survey by

the Geophysical Institute's seismic group revealed landslides on the south f :ing slopes of Hunter Creek, striking perpendicular to the aftershock zone (Gedney and others, 1969).

Another area of major activity is situated north of the Denali fault in the foothills of the Alaska Range and NW of BLR with three magnitude 5 to 5½ shocks during July, 1969, and associated aftershocks (see epicenter maps). Recurrence rates for the shocks recorded inside the network and strain release have been determined (see Fig. 3 and Fig. 4). Figure 4 was prepared by L. Gedney.

GEOLOGY, TECTONICS AND EARTHQUAKES

The following paper had been completed during this contract period but acknowledges the previous AFOSR Grant 701-66:

THE FAIRBANKS EARTHQUAKES OF JUNE 21, 1967; AFTERSHOCK DISTRIBUTION, FOCAL MECHANISMS, AND CRUSTAL PARAMETERS

by

Larry Gedney and Eduard Berg

ABSTRACT

A series of moderately severe earthquakes occurred in the vicinity of Fairbanks, Alaska, on the morning of June 21, 1967. During the following months, many thousands of aftershocks were recorded in order to outline the aftershock zone and to resolve the focal mechanism and its relation to the regional tectonic system. No fault is visible at the surface in this area.

Foci were found to occupy a relatively small volume in the shape of an oblate cylinder tilted about 30° from the vertical. The center of the zone lay about 12 kilometers southeast of Fairbanks. Focal depths ranged from near-surface to 25 kilometers, although most were in the range 9-16 km. In the course of the investigation, it was found that the Jeffreys and Bullen

velocity of 5.56 km/sec for the P wave in the upper crustal layer is very near the true value for this area, and that the use of 1.69 for the V_p/V_s ratio gives good results in most cases.

The proposed faulting mechanism involves nearly equal components of right-lateral strike slip, and normal faulting with northeast side downthrown on a system of sub-parallel faults striking N40°W. The fault surface appears to be curved - dipping from near vertical close to the surface to less steep northeast dips at greater depths. The relationship of this fault system with the grosser aspects of regional tectonism is not clear.

SOME CHARACTERISTICS OF THE TECTONIC STRESS PATTERN IN ALASKA

by

Larry Gedney and Eduard Berg

SUMMARY

Horizontal azimuths of tectonic 'pressure' are plotted for 38 small and intermediate earthquakes recorded in Central Alaska by a six station network during the period October 1967-September 1968. Two potential mechanisms were considered in evaluating P-wave data from the shocks. The first assumed lateral motion on vertical fault planes, while the second considered the possibility of normal faulting on vertical, or near vertical planes. Although many deeper-than-normal shocks occur in the region under investigation, they do not appear to be consistent with either of these simplified mechanisms. Of the 38 events considered, only one was at a depth significantly in excess of crustal thickness in the region.

The results of this study suggest that maximum tectonic pressure is being exerted in a direction normal to the continental margin in the area of Cook Inlet, while block-faulting is occurring in the northermost portions of the Alaska Range. Between these two areas, on the inside of the sharp

bend formed by the Alaska Range, maximum compressive stress is being exerted in a direction parallel to the mountain front, implying that further 'bending' of the range may be occurring. This is the condition which would be expected if this portion of the Alaska Range is performing in the manner of a hinge as is stated in Carey's (1956) 'Alaskan Orocline' theory of continental drift.

RECORDING OF SPECIAL EVENTS

Records of special events as obtained from the telemeter network have been transmitted to the contract monitor. These records include among others the three French tests in the Pacific on August 3, August 24, and September 8, 1968, and the event MILROW. Other interested persons or agencies also have obtained original films or copies as requested.

TRANSMISSION OF EPICENTER LOCATIONS TO THE SEISMIC ARRAY ANALYSIS CENTER

IBM SAAC required the epicenters, origin times and depths of earthquakes of magnitudes larger than three and located inside or close to the telemeter network of the seismic laboratory on a short time basis.

During the period from the end of April to the end of September, 1968, the seismic records have been analyzed, computer inputs prepared and the data obtained several times per week. This information on quakes with magnitudes larger than 3 was sent by phone directly to Washington, D.C., two to three times a week, where it was used for a special research program.

BOREHOLE INSTALLATION

Under this contract, the seismic laboratory inherited (as Government furnished equipment) three sets of borehole packages. Each package contains 3-component 1-sec short-period seismometers and 3-component 15-sec long-period pendulums and associated electronics. The short-period seismometers are of the Ranger type, the long-period instruments of the Lamont lunar or ocean-bottom type with remote-automatic leveling. The instruments had been

assembled by the Sandia Corporation for an "Unmanned Seismic Observatory" ("USO") and are described in some detail (Sandia, 1968).

<u>Site Selection, Installation</u>

Three sites have been selected to form a tripartite tilt network, to be useful for short and long-period data, and finally to permit telemetry back to the seismic laboratory. These sites are Gilmore (GLM), Paxson (PAX), and McKinley (MCK) (see Fig. 1A and Table). Drilling was started in GLM in September, 1968, and PAX in early November, 1968; however, the first driller had innumerable breakdowns so that PAX and MCK had been drilled by a second firm in April and May, 1969. The depths to the bottom of the casings are: GLM, 15 ft.; PAX, 38 ft.; and MCK, 28 ft.

The GLM package was installed in mid October, 1968, with the help of a three member Sandia Corporation group which had built and worked with the instruments. It was found that several hinges were broken on the two long period sets, which had been shipped to Alaska that summer. The 2 sets were sent back to Earth Sciences of Teledyne in Pasadena for repair. The instruments were accompanied on their return flight all the way to Fairbanks, to avoid further damage. These then were installed in PAX and MCK with the help of the same Sandia group as previously (summer of 1969) mentioned.

<u>Problems</u> (including barometric pressure effects on LP-X component)

Numerous problems had been encountered with the electronics: since the stations were now running on local power, the short period amplifiers automatic gain control had a nasty habit of resetting gains at random, if a short power failure occurred (since data were telemetered the gain setting could otherwise only be accomplished with "USO Test Set" because all timing and recording is at the Institute, so that no hourly pulses are available at the remote site for initiating the automatic gain setting. Since the

automatic gain control was in any event a very undesirable feature for a station where gain could be set by hand, we therefore installed hand operated switches instead of the gain control relays. After the PAX package was lowered and clamped in the hole it was found that the LP-Z component was not operative and that it was impossible to cage the instruments. The caging drive probably went beyond its stop switch and could turn freely so as not to come back between the guide pins.

Since Dr. P. Pomeroy wanted the long-period data from 20 to 200 sec, the feed back filter time constant was lengthened by Sandia from 1400 to 6000 sec. Occasional unpredictable instability occurred and circuits started oscillating (even still using Sandia's long-period amplifier peaking at 18 sec.). When the amplifiers obtained from Dr. Pomeroy finally were installed, very often the 3-component LP's went into in phase oscillations. In Paxson (as an example) this lasted for days (T_0 = 20 sec.) and the amplitude was just enough to fill the telemeter channel width. Sometimes the feedback channel also would oscillate in "level mode". It was found that the three Pomeroy amplifiers, mounted on a single rack-panel, were coupling among themselves (and perhaps also through ground loops). Finally, the demodulator outputs were telemetered, first from Paxson and Gilmore, and the Pomeroy amplifiers added after discrimination. But, once more, two Pomeroy amplifier panels could not be run off the same power supply without serious coupling problems so, finally we put each on a different supply, batteries or others. This decoupling, first from the borehole electronics (through the transmission link), second between sets of amplifiers showed good results: the gain from ground to trace motion on the recording paper was around 29K, with p-p noise (during quiet periods) of only several millimeters, but at noisy times, just about the full width of the chart year (± 25mm) was noise.

During the analysis of the tilt recordings it was first found that in both, GLM and PAX, the X component showed large variations almost identical (amplitude and phase) at both stations, whereas the Y components were relatively stable. Later MCK-X also showed the same effect except for even higher amplitudes. Transmission of data or tectonics could not be responsible: telemeter links were of quite different types and the X component was to the north in GLM, to the east in PAX and MCK. The effect was traced to barometric pressure variation, the full spectrum from 15 sec. to DC. Since the boreholes had various covers, the "calibration" constant for recording barometric pressure for the package as such cannot be given, but for the particular GLM set with two five inch foam rubbers pushed inside the casing (to stabilize the air) the pressure-induced displacement of the X transducer was -14 mμ/μ bar at periods longer than the seismometer period (>15 sec) but short compared to the feed back time constant (6000 sec, infrasonic gravity wave spectrum). Using the Pomeroy amplifier after the demodulator output, this amounts to -40 mV/μbar. The feedback loop reduces this by 30 db after it becomes effective (T > 6000 sec). As a consequence a -1.8 sec arc/inch mercury variation in tilt was simulated, enough to read the barometric pressure to about 5/1000 inch mercury on the output of the X feedback signal or simulate a 5 sec/arc tilt over a two day period. This finding advanced us into the early winter. Therefore we only sealed the close-by GLM borehole casing against air pressure variation and the whole effect disappeared. Amplitudes are commonly about 1 to 2 mm p-p (at 29 k gain) on the LP X output (Fig. 11) and it is not certain whether that is not transmission noise rather than seismic noise because that is 10 to 15 db lower than the manufacturers claim for the telemetry FM equipment. At present we are experimenting to clarify this point and others. A special report with more detail on the barometer effect will be prepared.

To compound difficulties, the electronic technician, who had been with the seismic laboratory for four years left in April, 1969, so that the principal investigator spent most of his time to the end of 1969 to get the instruments working properly. However, some results have been already obtained (see later section and Berg, 1969).

CRUSTAL PARAMETERS FOR CENTRAL ALASKA

The following contribution has also been financed through a National Science Foundation grant. It involves, however, a heavy use of the telemeter system data. The data analysis has been carried out by John Davies in close contact and discussion with the principal investigator.

In July, 1968, an attempt was made to utilize the telemeter network along with several USC & GS stations and three temporary vertical component stations to make a preliminary crustal study, using the regions with frequently occurring earthquakes as energy sources. This method was decided upon because the usual methods of explosion profiling are restricted due to the large areas involved and the sparse road system.

It was found that the phases arriving after the first one could not always be identified reliably enough to provide a profile of the crustal layering. In cases where Pn was not first arrival and could not be seen, J-B table time differences were assumed to hold, so that a Pn arrival time could be calculated. This was necessary to have more widespread earthquake coverage. Pn velocities so obtained are plotted on the summary map (Fig. 5). They range from 6.8 to 10.6 km/sec and with what one would expect from general isostatic compensation for the mountain systems in the region and with the previous work of Hanson and of Sherburne, and others, Tuve and Tatel, Woollard, and Hales and others. There are some exceptional results in the Palmer area. It is not known if

these are reliable indications of the structure, but geological and gravimetric considerations show this to be a very complex area. So perhaps these results are not so surprising.

It can be concluded that this method can yield indications of the structure but that it cannot provide unequivocal results. If there were several seismometers at each station (small tripartite net or an L-shaped spread) so that cross correlation methods could be used to pick all the phases reliably (by determination of phase velocity) the technique of using earthquakes as an energy source in regions of high seismicity could be very profitably employed in Alaska. Use of horizontal components would also improve phase indentification.

The following table shows the Pn velocities found between station pairs (in the same direction), and Fig. 5 shows the averaged velocity together with the direction of wave travel for which it has been determined.

MATERIAL FAILURE IN AN EARTHQUAKE ZONE, AS CONCLUDED FROM SMALL EARTHQUAKES

RELATION BETWEEN EARTHQUAKE, FORESHOCKS, STRESS AND MAINSHOCKS

by

Eduard Berg

ABSTRACT

"The slope "b" of the Gutenberg-Richter relation log N = a + b (8-M) for different foreshock series is related to the magnitude of the succeeding main earthquake. A separation of the values of "b" of foreshock series and aftershock series is clearly indicated. If the same stress levels relative to the breaking stress are indicated by "b" of earthquake foreshocks as they are in laboratory measurements, small "b" values in an earthquake zone will be associated with high relative stress levels and a following mainshock of small magnitude, whereas larger "b" values indicate larger stressed areas and a larger

JB CORRECTED APPARENT MONO VELOCITIES

BLR-PJD	BLR-SCM	MCK-PJD	MCK-TNN	PMR-BLR	PMR-PMS	PMR-PMW	PMR-SCM	PMR-SVW	PMR-TAL	PMS-BLR	PMS-PMR
8.14	7.26	9.08	8.15	6.95	7.65	6.44	6.49	8.79	9.26	6.8	7.84
		8.05		8.02	7.42	7.82	8.6		9.53		9.78
		8.45		7.64	6.86	6.23	8.50				(11.4)
		8.73			7.9	6.9					11.
		9.5			7.6	8.4					11.
		8.70			6.5						10.
		8.16			(7.42)						
		8.42									
		8.55									
		8.4									
		8.52									
		8.43									

PMS-PMW	PMS-SCM	PMS-SVW	PMW-BLR	PMW-PMR	PMW-PMS	PMW-SVW	RED-BIG	RED-PMS	RED-SVW	RED-KOD	SCM-BLR
6.85	9.12	8.18	8.19	7.9	6.94	8.33	8.58	10.6	8.54	8.65	7.59
7.16	8.46	8.20	7.15		6.89	8.20	7.04				7.89
6.69	6.68	8.04	8.30		6.36		6.44				7.6
10.3	9.25	8.44	9.24		6.96						7.58
	9.30	8.38	8.17		6.6						7.43
	11.9				7.5						8.1
	8.86				7.5						7.14
	(15.2)				7.5						
					7.0						

SCM-MCK	SCM-PJD	TAL-MCK	TAL-PMR	TAL-PMW	TAL-SCM	TAL-SVW	TAL-TNN	SCM-TAL	SVW-BIG
7.45	7.80	7.52	(11.4)	(10.3)	8.1	9.22	7.5	7.10	8.04
7.42	7.94	9.2		(11.9)	10.4	8.50	8.4		
7.40		6.62		(12.5)		9.25	7.66		
7.46		7.35		(14.5)					
		7.22							
		6.92							

following main shock. However, all "b" values for foreshocks are lower than those for ncrmal seismic activity or the aftershock series."

It has been shown on rock samples in the laboratory that microfracturing prior to ultimate failure can be directly related to the applied stress and the resulting strain. This microfracturing is found to follow the same empirical Gutenberg-Richter relation as do earthquakes. The slope of log N = a + b (8-M), "b", during the microfracture process of laboratory samples is a function of the percentage of stress relative to the final breaking stress. In an earthquake area relatively high stress levels appear characteristic for small main shocks (identified by low "b" values) whereas higher "b" values indicate lower relative stresses leading to larger failures (see Berg, 1968).

During 1968-69, small shocks in the aftershock zone of the 1967 Fairbanks quake revealed short period fluctuations of "b". The "b" remained almost constant for several months after the main shock as intense aftershock activity continued, but begun fluctuating considerably as the activity died off. As an example during the period August 27 to September 2, 1968, the slope "b" dropped from about 1.0 to 0.5 prior to two earthquakes of magnitude 4.9 and 3.8 on September 2, 1968 (Fig. 12).

If the laboratory results are assumed valid for rocks in situ in a seismically active zone, this change in slope could be interpreted as a relative stress increase from the 20% to 50% level to the 80% to 100% level. There was also a considerable increase in number of quakes in the magnitude range -0.5 to 1.0 during this time: 17 events on August 27 increasing to 40 on September 1. This seems to indicate a rapid build-up of stress and strain release in a small area. The times involved - several days - are comparable to those observed for other preceding phenomena such as fault creep, change in earth magnetic field intensity and crustal strains and tilts.

Since stress measurements in the crust are nearly impossible, the preceding approach may open new avenues in understanding the crustal deformation process. The simultaneous use of tilt recordings (which had not yet been available at the time of the preceding investigation) from the tripartite borehole network will give a better understanding of the mechanism.

TILTS ASSOCIATED WITH SMALL EARTHQUAKES

Earthquake-associated tilts have been reported in the literature from various continents and quite different instrumentation. Recording of tilts from low magnitude earthquakes is relevant to the problem of source functions. In Russia and Japan, tilts also have been used successfully to predict impending earthquakes. However, often the reliability of "tilts" as recorded on horizontal seismograms has been questioned. One might either use the direct optical recordings such as from the Wood-Anderson torsion seismometer, The Verbaandet-Melchior All Quartz Pendulums (Verbaandert and Melchior, 1960) or the long-period horizontal instruments with modern high sensitivity displacement transducers, such as the ones installed in the three borehole packages. One attempt to obtain the tilt associated with local earthquakes form the interpretation of velocity transducers was made by Berckhemer and Schneider (1964). Hagiwara reports (1969) that "We often observed sharp changes in tilting a few hours before the occurrence of earthquakes of about magnitude 5. Such short range changes just before a large earthquake were clearly observed with the water tube tilt meter, but they were not detectable by the pendulum type tilt meter. The reason why the water tube tilt meter indicates such changes and the pendulum tilt meter does not, is not entirely clear but one solution will be proposed. For the long range changes in tilt, observational results of the water tube tilt meters and the pendulum tilt meters coincided well with each other."
A limited number of papers on earthquake-associated tilt are given in the reference section. The first recordings from GLM were obtained in June, 1969.

After the elimination of transmission-link-generated 24-hour variation (see Fig. 6, PAX record) records of the tilt were plotted as in Fig. 7. One of the major difficulties in obtaining the correct tilt rate over long time periods is due to the automatic releveling of the instrument supporting gimbal-mounted platform. The releveling is initiated whenever the feed back signal reaches about plus or minus 1.3 volts or an equivalent of ± 6 sec arc. An annoying releveling occurred 6 hours prior to the PJD earthquake (Mag. 4.6) on June 21, 1969 (Fig. 7). Usually one only can connect data points prior to and after the leveling as done in Figs. 6 and 7. No level change occurred on the June 21 record in the E-W direction (GLM-Y, Fig. 7).

Reliability of Pendulum Tilt Measurements

The question of residual and transient deformation in the earth crust has a renewed interest, since Ryall and others (1969) discovered that the larger underground explosions were associated with aftershocks. The pre-existing tectonic stress and the explosion-induced transient strain seem to be responsible for triggering subsequent earthquakes (Smith, 1969, Smith and others, 1969), but little is known to date on these stress levels and the time variation of the transient deformation of small-magnitude earthquakes (see also Romig and others). This is important to determine adequate source functions. Press (1965) has given theoretical values for tilts associated with dip and strike slip faulting. Figure 8 shows the summary of his results, presenting a more easily recognizable presentation of the total tilt field than in his original paper. Berckhemer and Schneider found by integration from the long-period seismometers velocity transducer tilts of 0.05 sec arc at Δ = 63 km for a M = 4.5 shock and 0.008 sec arc at Δ = 164 km for a M = 5 shock. Press (1965) questions such results. There

are, however, a number of good arguments to accept such tilts as real. Tilts have been recorded on either liquid type or horizontal pendulum type instruments, using a variety of transducer-recording combinations. All have yielded similar results. The amplitude-distance values given by Berckhemer and Schneider compare to a tilt of about 0.2 sec arc recorded during the PJD June 21 quake ($M = 4.6$ $\Delta = 15$ km) and a 0.1 arc sec tilt during the magnitude 4-¼ quake in the general Fairbanks area (as recorded at GLM) (Fig. 9). In both cases the tilt was not recognizably recovered. Also the Rampart (Mag. = 6½) earthquake (Oct. 1968) was associated with an offset corresponding to a 1.5 sec arc tilt to the south and 0.74 sec arc to the west on the College USC & GS Wood-Anderson seismometers (prior to the installation of GLM). The distance from the station to the epicenters was about 120 km. All these numbers compare reasonably with each other.

The principal investigator analyzed a few days of records from the LWI, AST, RUM, and UVI stations in the African rift system in the eastern part of the Congo and Ruanda. Included were records from a foreshock which showed first motion distribution and tilts (offsets on the Wood-Anderson) in the opposite direction from the main shock and the larger aftershocks. Tilts on two locations (LWI and AST) on opposite sides of the rift some 140 km from the epicentral area (northern end of Lake Tanganyika) were directed away from the rift and towards the north (away from the epicenter). They showed about the same amplitude.

GLM Tilts, 21 June and August 25, 1969

The first earthquake-associated tilt clearly observed was recorded at GLM on June 21, 1969. Using Jeffrey-Bullen travel time tables and the P-wave arrivals at the stations MUR, GEO, PJD, GIL, GLM and MCB, the epicenter of the earthquake in question was located at some 8 km NNE of PJD

and the focal depth determined to 20 km. First motion in the S-W quadrant (including TNN) was compression, GLM, MCB and BLR registered dilatation. The direction of the tilt was northeast (see Fig. 10). The station GEO is on campus, northwest of Fairbanks. Tilts and first motion patterns are consistent with an essentially dip slip fault. The strike (to the NNE) is a line through the epicenter separating the stations recording compression and recording dilatations. The direction of the tilt is consistent with a dip slip fault if the X_1 axis of Fig. 8 is pointed NNE, (GLM being close to the axis of the fault prolongation on the down drop side). The fault plane solution is similar to one of the possibilities of the Fairbanks, 1967, M = 6 quake (Gedney and Berg, 1969) in that it indicates a compressional stress from the south to southeast, also in agreement with the geology. In particular, the tilt component toward the north is consistent with the observation that the Chatanika River flows along its northern abutment. The epicenter was in the Chatanika Valley. One might possibly speculate that this quake, its aftershocks and the June 1967 Fairbanks quake are part of a same fracture or zone of weakness. The onset of the tilt is clearly visible some 10 sec after the arrival of the P-wave but the 6000 sec response time constant of the filter in the feedback network prevents any closer analysis, at the signal/noise ratio at that time. This would indicate, however, a strain propagation velocity similar to that reported by Romig and others (1969) of the order of 1 to 3 km/sec but for a much smaller magnitude quake.

A second case was recorded with the Aug. 25, M = 4-½ quake in the Fairbanks area 14 km south of GLM at a depth of 23 km (see Fig. 9). Total tilt was about 0.1 sec arc.

We are at present experimenting with using the demodulator output (after amplification) for recording short-term tilt variations (with time

constants small compared to the 6000 sec feedback filter time constant). An interesting record was thus obtained on January 16, (see Fig. 11).

Trace one is the DEM-X signal from the Gilmore borehole (GLM), telemetered to the Geophysical Institute, then recorded through the Pomeroy 20 to 200 sec passband amplifier (gain 115). Trace 2 is the same transmitted DEM-X signal, but through a 12 sec low pass RC filter and amplified 75 times. Traces 3 and 4 are similarly recorded for the Y component and trace 5 is the DEM-Z signal through the Pomeroy amplifier. Time marks after trace 4 are at 1 min. intervals. The first signal at GLM is from a local Fairbanks quake ($M = 3\frac{1}{2}$ to 4), the second from a larger south central Alaska quake. No DC (tilt) offset could be observed after the traces 2 and 4 returned to their quiet state in about an hour. If the initially observed offset to the SE is a real tilt, the feedback would have diminished that amplitude by 30 db (a factor of 31.6). That small a tilt is not recognizable any more in the prevailing background noise under the set-up of trace 2 and 4.

We continue to experiment with other filter-amplifier combinations to eliminate more of the 7 sec period seismic background noise.

Results so far obtained, mostly at GLM, are very promising and we are looking forward to use the PAX and MCK records in a similar manner once the boreholes can be sealed against the major noise source, the atmospheric pressure variation.

PAPERS ACKNOWLEDGING AFOSR SUPPORT

Berg, Eduard, Relation between Earthquake Foreshocks, Stress and Mainshocks, Nature, Vol. 219, No. 5159, pp. 1141-1143, 14 Sept. 1968.

Gedney, Larry and Eduard Berg: Some Characteristics of the Tectonic Stress Pattern in Alaska, Geophysical Journal, Royal Astronomical Society, Geophysical J. Royal Astr. Soc. 17, 293-304, 1969.

Gedney, Larry, Eduard Berg, Hans Pulpan, John Davies, and William Feetham: A Field Report on the Rampart, Alaska Earthquake of October 29, 1968, Bulletin of the Seismological Society of Am., Vol. 59, No. 3, June 1969.

Paper given at the National Fall Meeting of the AGU 1969:
Eduard Berg and Hans Pulpan, Tilts Associated with a local Earthquake Magnitude 4.6 at Delta = 15 km (Abstract: Transaction, American Geophysical Union, Vol. 50, No. 11, p. 645, Nov., 1969).

Report in Preparation:
Eduard Berg and Ronald Rasmussen: The Effect of Barometric Pressure Variation on the "USO" Longperiod Seismometer.

REFERENCES

Berckhemer, H. and G. Schneider, Near Earthquakes Recorded with Longperiod Seismographs, Bulletin of the Seismological Society of America, Vol. 54, Nr. 3, p. 973-985, June 1964.

Berg, Eduard, Larry Gedney, Susumu Kubota, Ken Hanson and Jurgen Kienle, The June 21, 1967, Earthquake Series at Fairbanks, Alaska: Aftershock Locations, Depths, and Magnitudes, Geophysical Institute, Univ. of Alaska, Scientific Report UAG-R-193, July 1967.

Berg, Eduard, Norbert Sperlich and William Feetham, Large Aperture Seismic Telemeter System for Central Alaska, Geophysical Institute, University of Alaska Research Report, UAG-R-188, July 1967.

Berg, Eduard, Relation between Earthquake Foreshocks, Stress and Mainshocks, Nature, Vol. 219, No. 5159, pp. 1141-1143, 14 Sept. 1968.

Berg, Eduard, Tilts Associated with a Local Earthquake Magnitude 4.6 at Delta = 15 km, Abstract, Transactions, American Geophysical Union, Vol. 50, No. 11, Nov. 1969, p. 645.

Bonchovsky, V. F., Deformation of the Earth's Surface Preceding and Accompaning a Catastrophic Earthquake, English Edition, Bull. (Izvestia) Acad. Sci., USSR, Geophysical Series, pp. 644-645, 1958.

Bonchkovsky, V. F., Deformations of the Earth's Surface Accompanying Certain Disastrous Distant Earthquakes, Bulletin (Izv.) Geophys. Ser., pp. 190-193, 1962, (English ed.).

Gedney, Larry and Eduard Berg, The Fairbanks Earthquake of June 21, 1967; Aftershock Distribution, Focal Mechanisms, and Crustal Parameters, Bulletin of the Seismological Society of America, Vol. 59, No. 1, pp. 73-100, February 1969.

Gedney, Larry, Eduard Berg, Hans Pulpan, John Davies and William Feetham, A Field Report on the Rampart, Alaska Earthquake of October 29, 1968, Bulletin of the Seismological Society of America, Vol. 59, No. 3, pp. 1421-1423, June 1969.

Gedney, Larry and Eduard Berg, Some Characteristics of the Tectonic Stress Pattern in Alaska, Geophysical Journal of the Royal Astronomical Society, Vol. 17, pp. 293-304, 1969.

Hagiwara, Takahiro, Observations of Tilting of the Ground due to Matsushiro Swarm Earthquakes, Transactions, American Geophysical Union, Vol. 50, No. 5, p. 391, May 1969.

Hanson, Kenneth, Eduard Berg and Larry Gedney, A Seismic Refraction Profile and Crustal Structure in Central Interior Alaska, BSSA Vol. 58, No. 5, pp. 1657-1665, Oct. 1968.

Hales, A. L. and T. Asada, Crustal Structure in Coastal Alaska, in the Earth Beneath the Continents, Geophysical Monograph No. 10, American Geophysical Union, Washington, pp. 420-432, 1966.

Herrin, E., Seismological Tables for P., Bulletin of the Seismological Society of America, Vol. 58, No. 4, p. 1196, Aug. 1968.

Karmaleeva, R. M., An Attempt to Forecast the Time of Near Earthquakes, Bulletin (Izv.) Geophys. Ser. 1960, pp. 467-474.

Karmaleeva, R. M., On Certain Coincidences Between Anomalous Tilt and the Occurrence of Earthquakes, Bull. (Izvestiya), Acad. of Sci., USSR, Geophys. Ser., No. 11, Nov. 1962, p. 970,(Engl. ed.,) 1962.

Nishimura, Eiichi, On Tilting Motion of the Ground Before and After the Occurrence of an Earthquake, Trans. Amer. Geophys. Union, 34, No. 4, pp. 597-599, 1953.

Nishimura, Eiichi, Some Problems of Tilting Motion of the Ground, Deuxieme collogue international de la commission du CSAGI pour l'étude des marées terrestres, Munich, Juillet, 1958, No. 142, pp. 100-110, 1958.

Press, Frank, Displacements, Strains and Tilts at Teleseismic Distances, J. Geophysical Res., 70, pp. 2395-2412, May 15, 1965.

Romig, P. R., M. W. Major, C. J. Wideman and D. Tocher, Residual Strains Associated with a Nuclear Explosion, Bulletin of the Seismological Society of America, Vol. 59, No. 6, pp. 2167-2176, Dec. 1969.

Sandia Laboratories, USO (Unattended Seismological Observatory) Final Evaluation Report, SC-M-68-60, April 1968.

Sherburne, R. W., S. T. Algermissen and Samuel T. Harding, The Hypocenter, Origin Time, and Magnitude of the Prince William Sound Earthquake of March 28, 1964, in: The Prince William Sound Alaska, Earthquake of 1964 and Aftershocks, Vol. IIB, Publication 10-3 (C&GS), U.S. Government Printing Office, pp. 49-69, 1969.

Smith, Stewart W., Transient and Residual Strains Associated with Large Underground Explosions, Abstract Transaction, American Geophysical Union, Vol. 50, No. 4, April 1969, p. 249.

Smith, Stewart W., Charles B. Archambeau and William Gile, Transient and Residual Strains from Large Underground Explosions, Bulletin of the Seismological Society of America, Vol. 59, No. 6, pp. 2185-2196, December 1969.

Tatel, H. E. and Merle A. Tuve, Seismic Explorations of a Continental Crust in: Crust of the Earth, Geological Society of America, Special Paper 62, Edited by A. Poldervaart, pp. 35-50, 1955.

Verbaandert, J. and P. Melchior, La Station de Pendules Horizontaux de Sclaigneaux (Province de Namur), Communications de l'Observatoire Royal de Belgique No. 170, Série de Géophysique No. 54, Bulletin de l'Académie royale de Belgique (Classe des Sciences) pp. 1084- 1086 Séance du samedi 6 février 1960.

Woollard, G. P., N. A. Ostenso, E. Thiel and W. E. Bonini, Gravity Anomalies, Crustal Structure and Geology in Alaska, Journal of Geophysical Research, Vol. 65, No. 3, pp. 1021-1037, March 1960.

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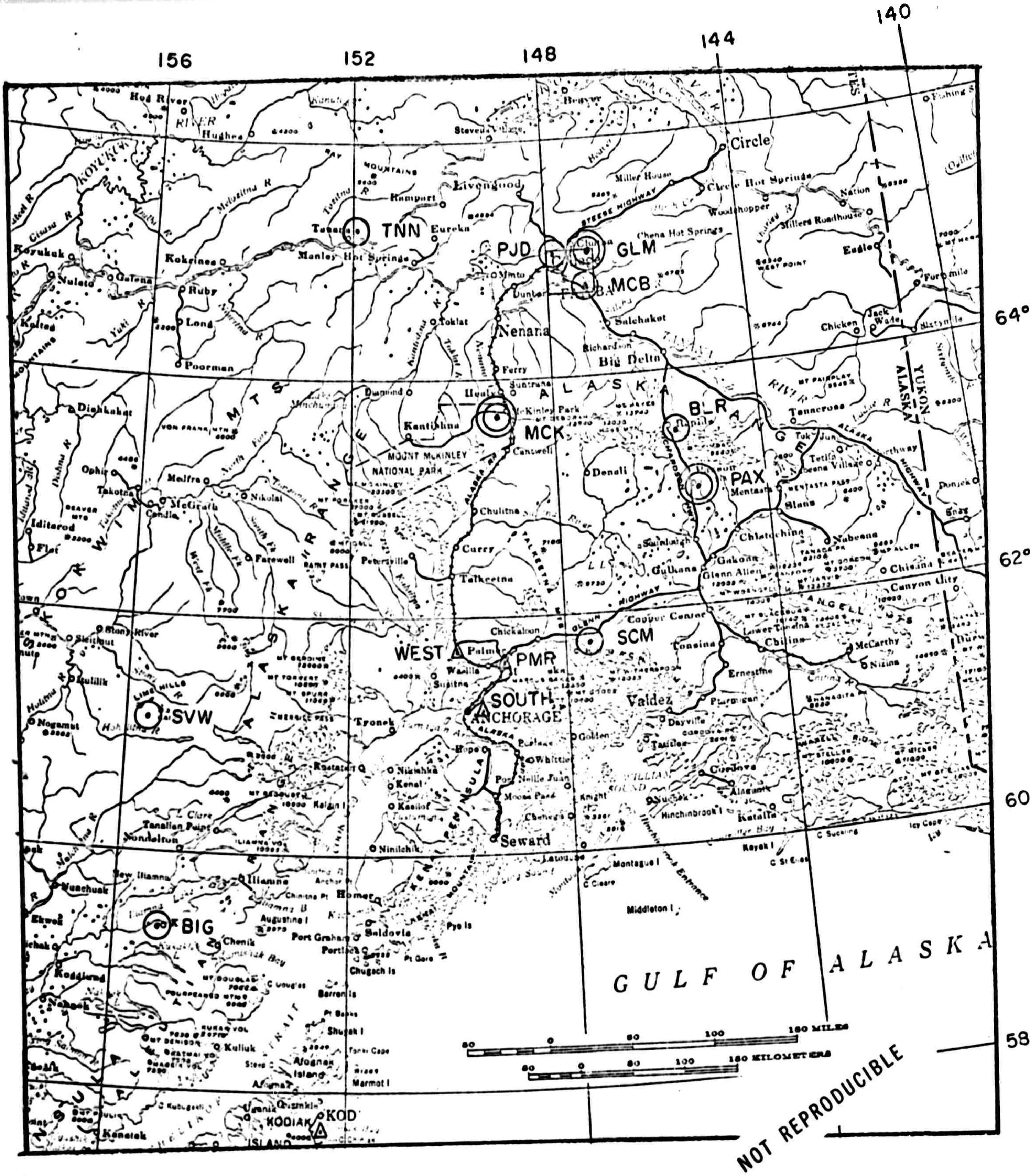


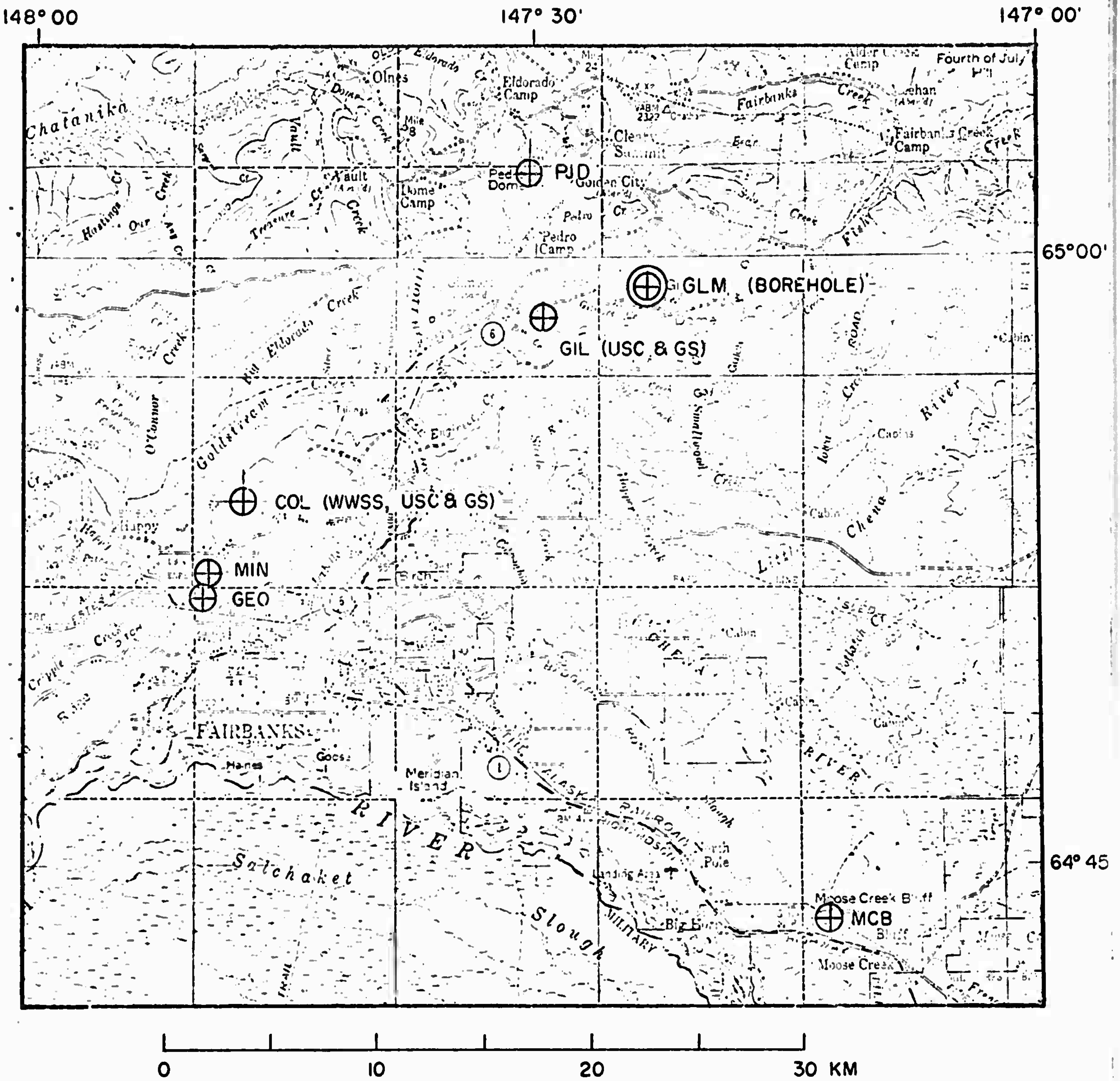
ALASKA TELEMETER SEISMOMETER STATIONS

UNIVERSITY OF ALASKA ⊙ VERTICAL SEISMOMETERS

◎ BOREHOLE INSTRUMENTS

U.S. C.&G.S. △ TSUNAMI WARNING NETWORK

Fig. 1. A. Alaska Seismometer Stations.



FAIRBANKS AREA SEISMOGRAPHIC STATIONS

Fig. 1. B.

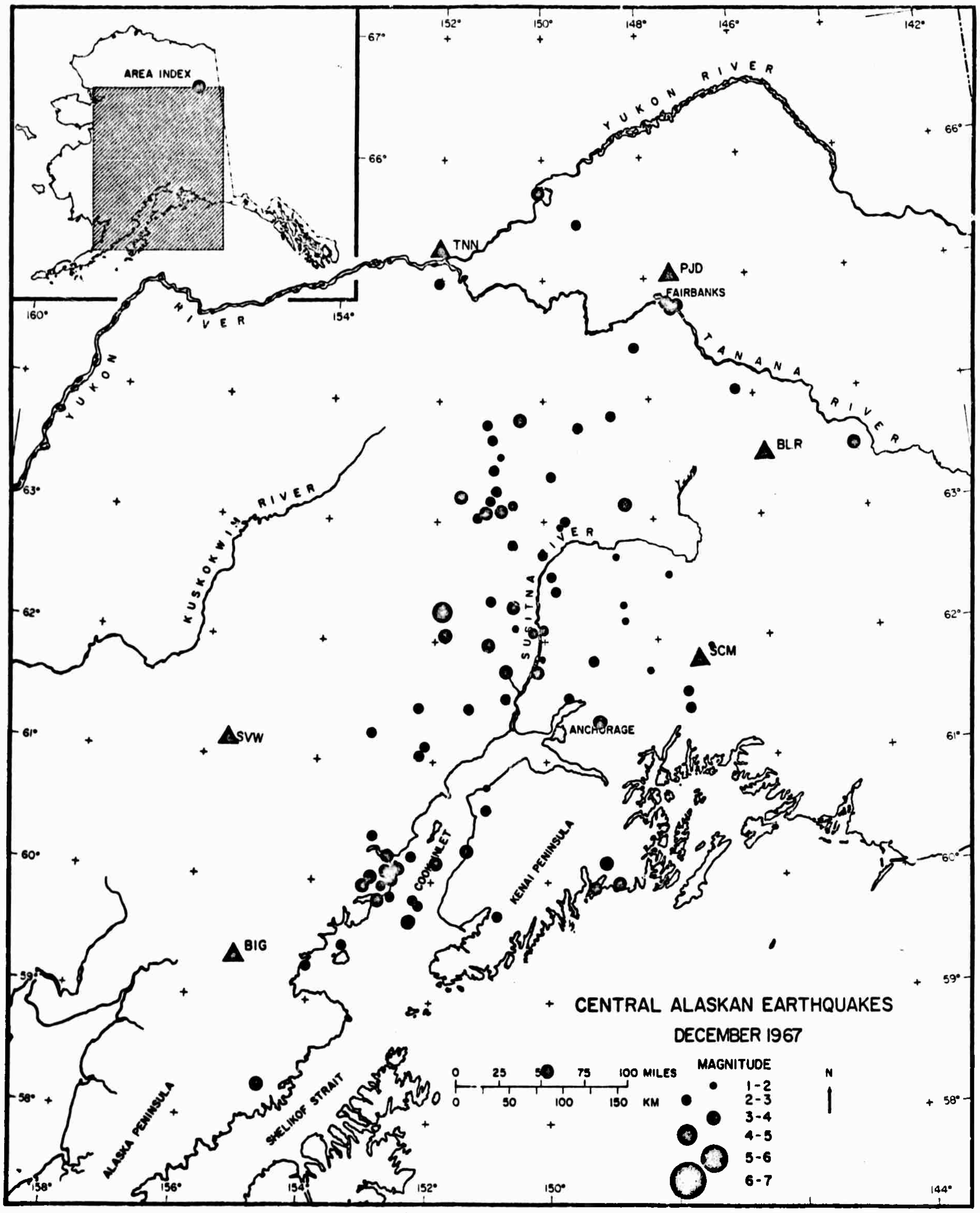
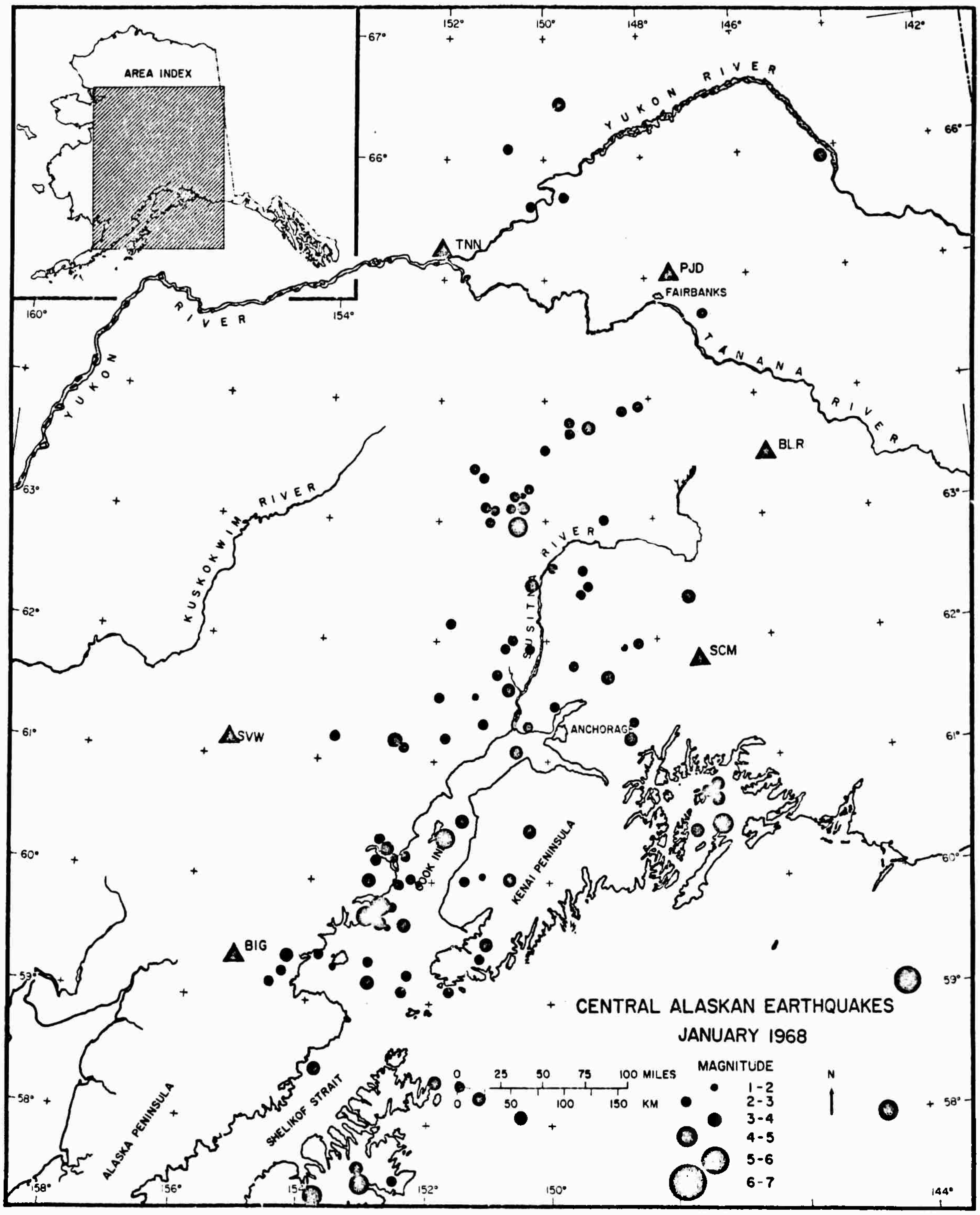


Fig. 2. A.

Monthly Epicenter Maps December 1968 through October, 1969.



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BIG
ALASKA PENINSULA
SHELIKOF STRAIT
CENTRAL ALASKAN EARTHQUAKES
JANUARY 1968
0 25 50 75 100 MILES
0 50 100 150 KM
MAGNITUDE
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Fig. 2. B.

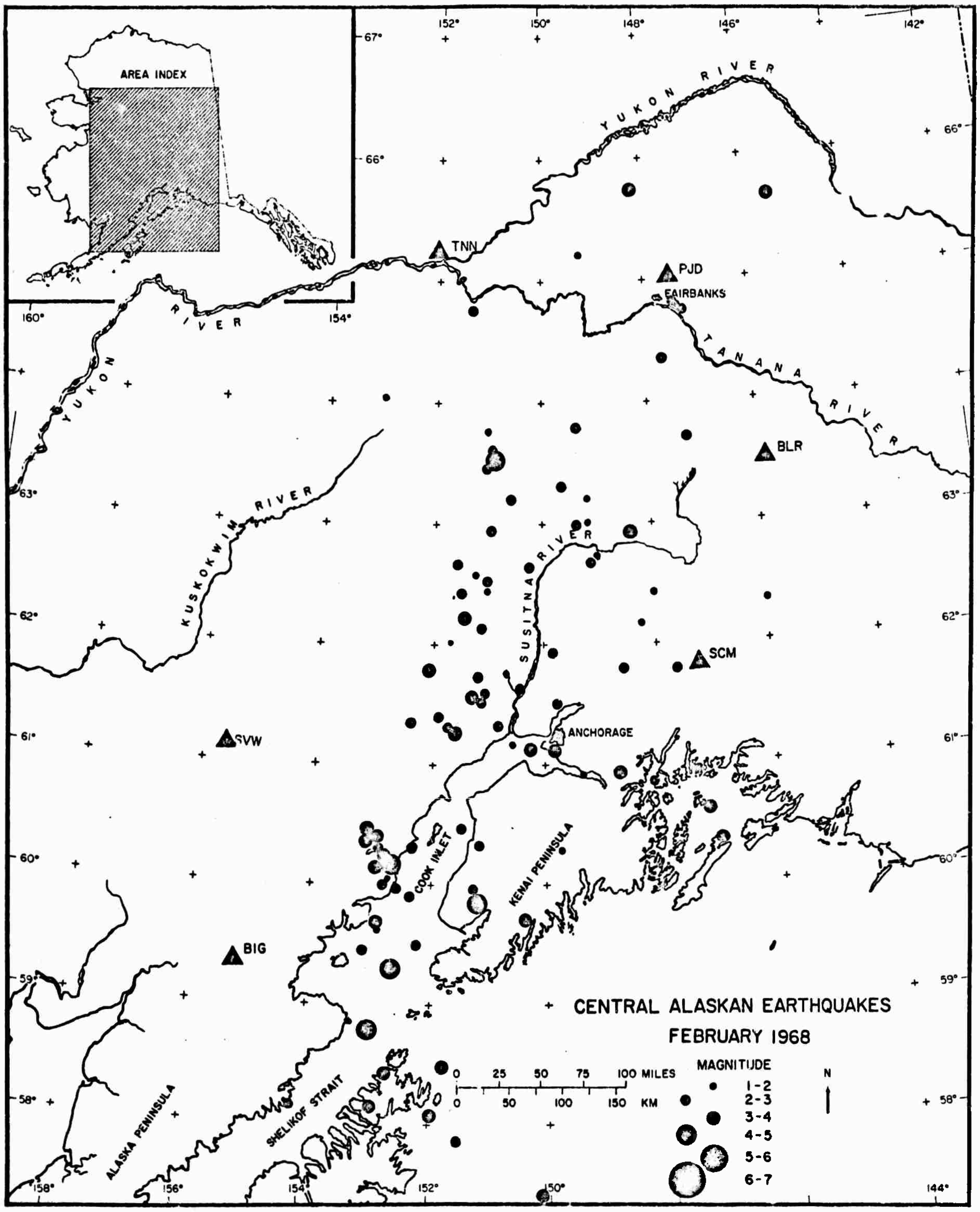

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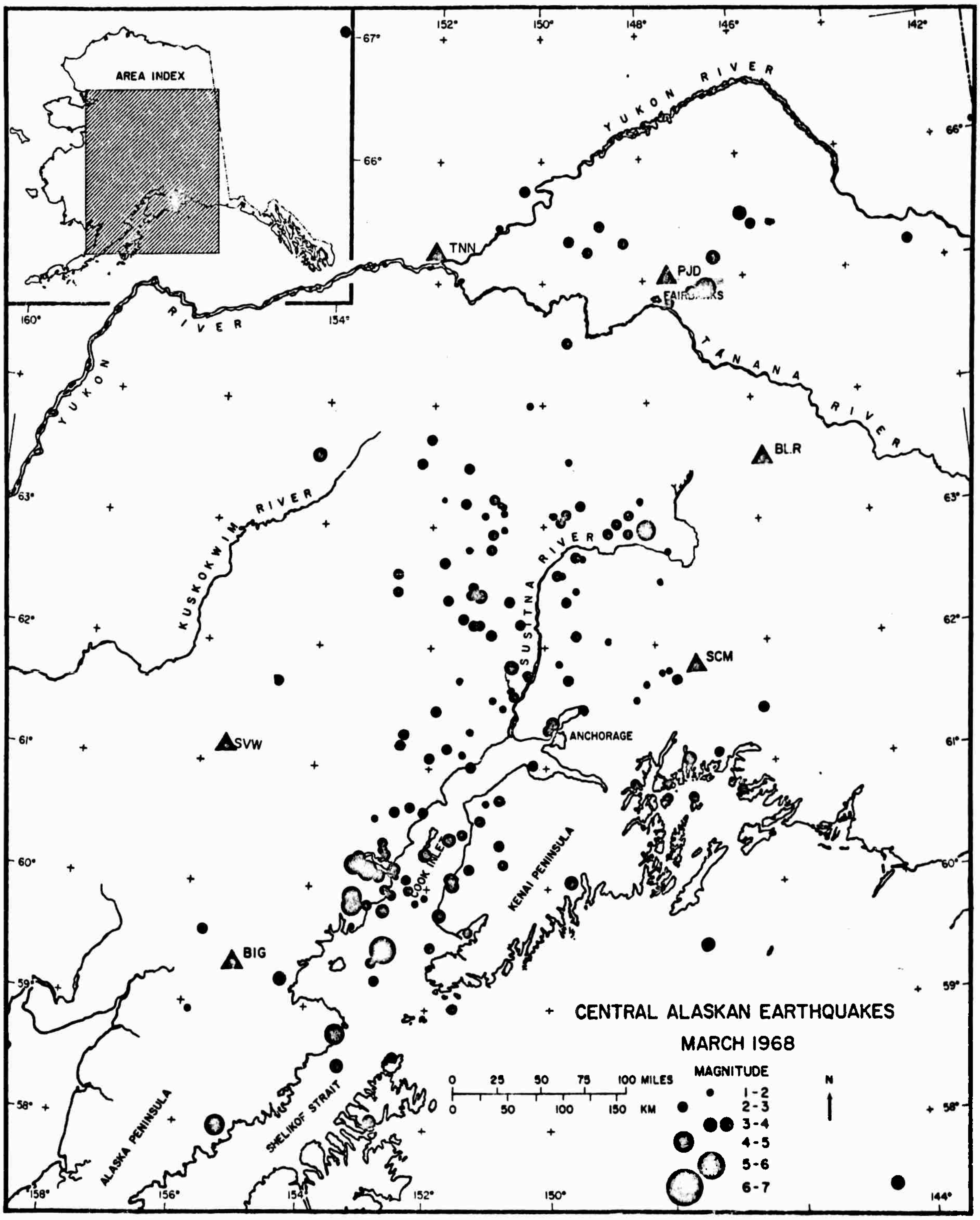
Fig. 2. C.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5-6
6-7
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Fig. 2. D.

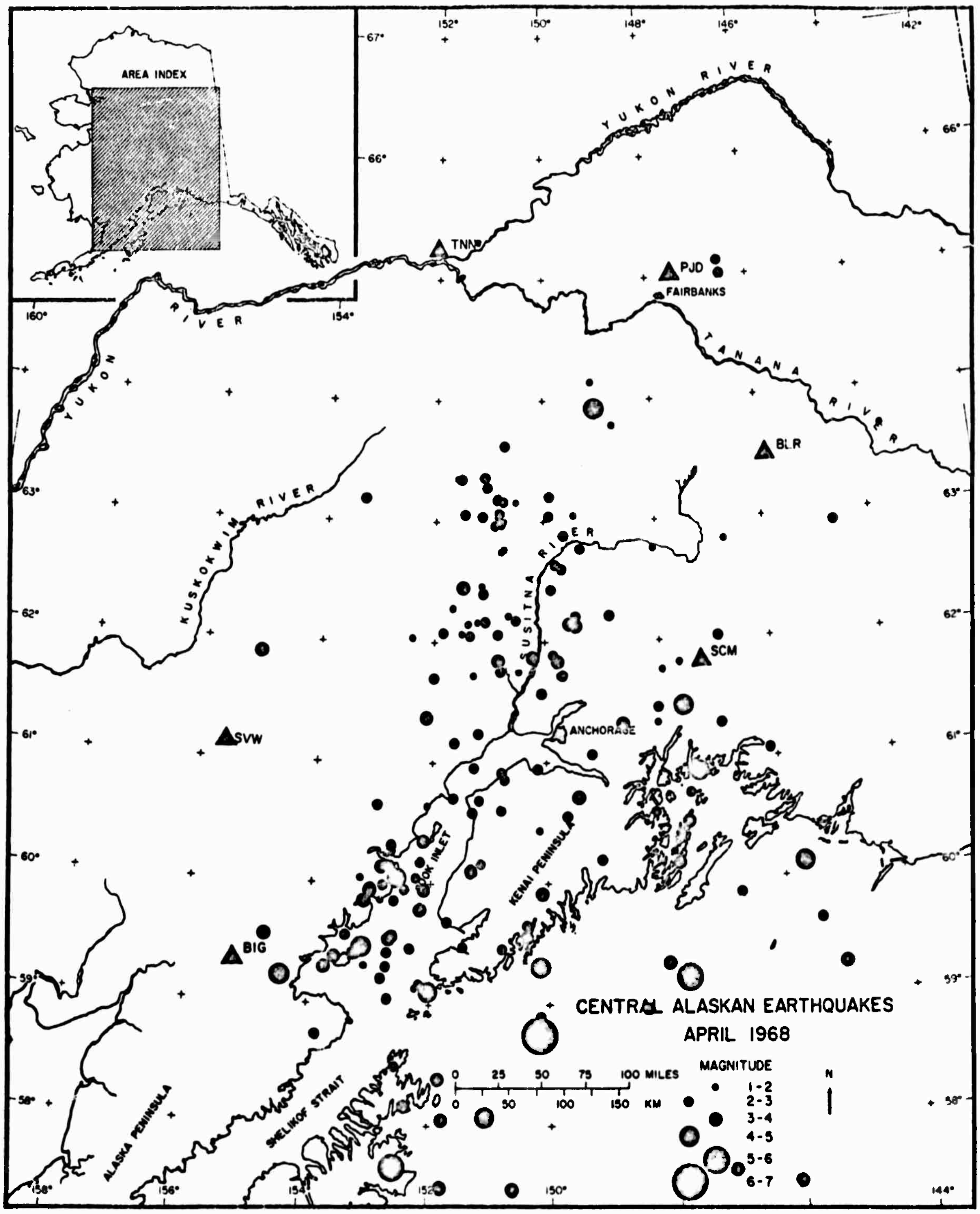
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Fig. 2. E.

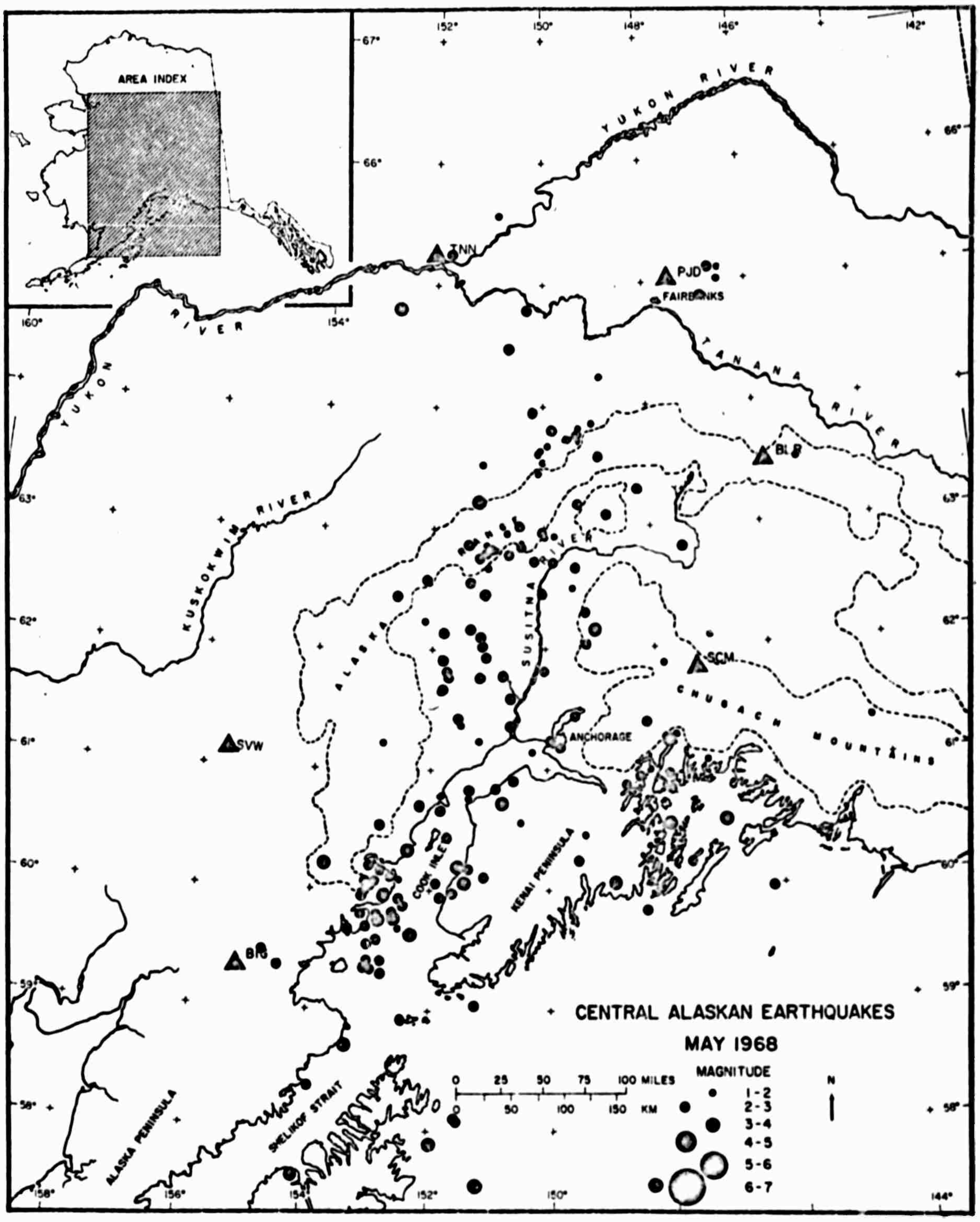
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Fig. 2. F.

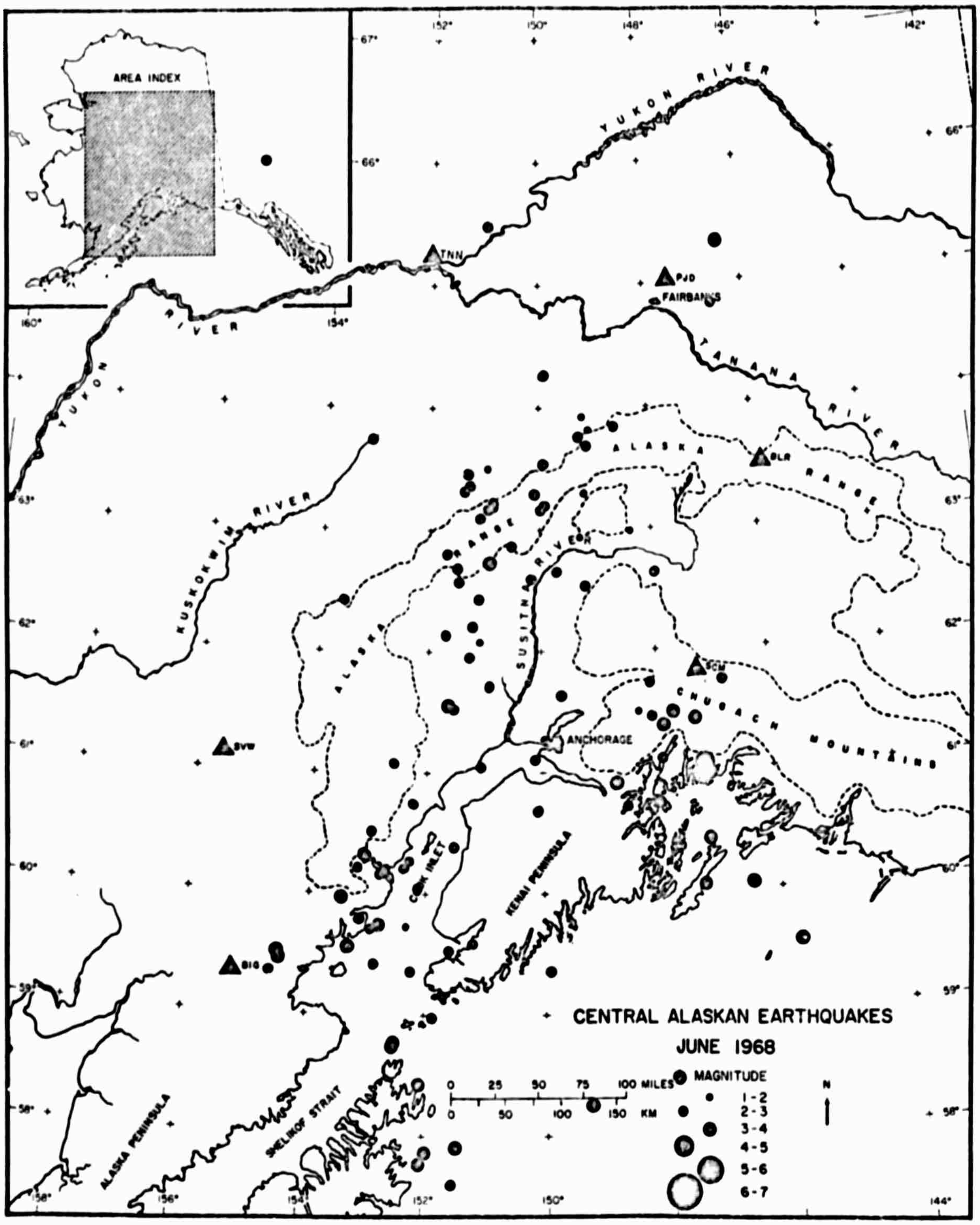

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Fig. 2. G.

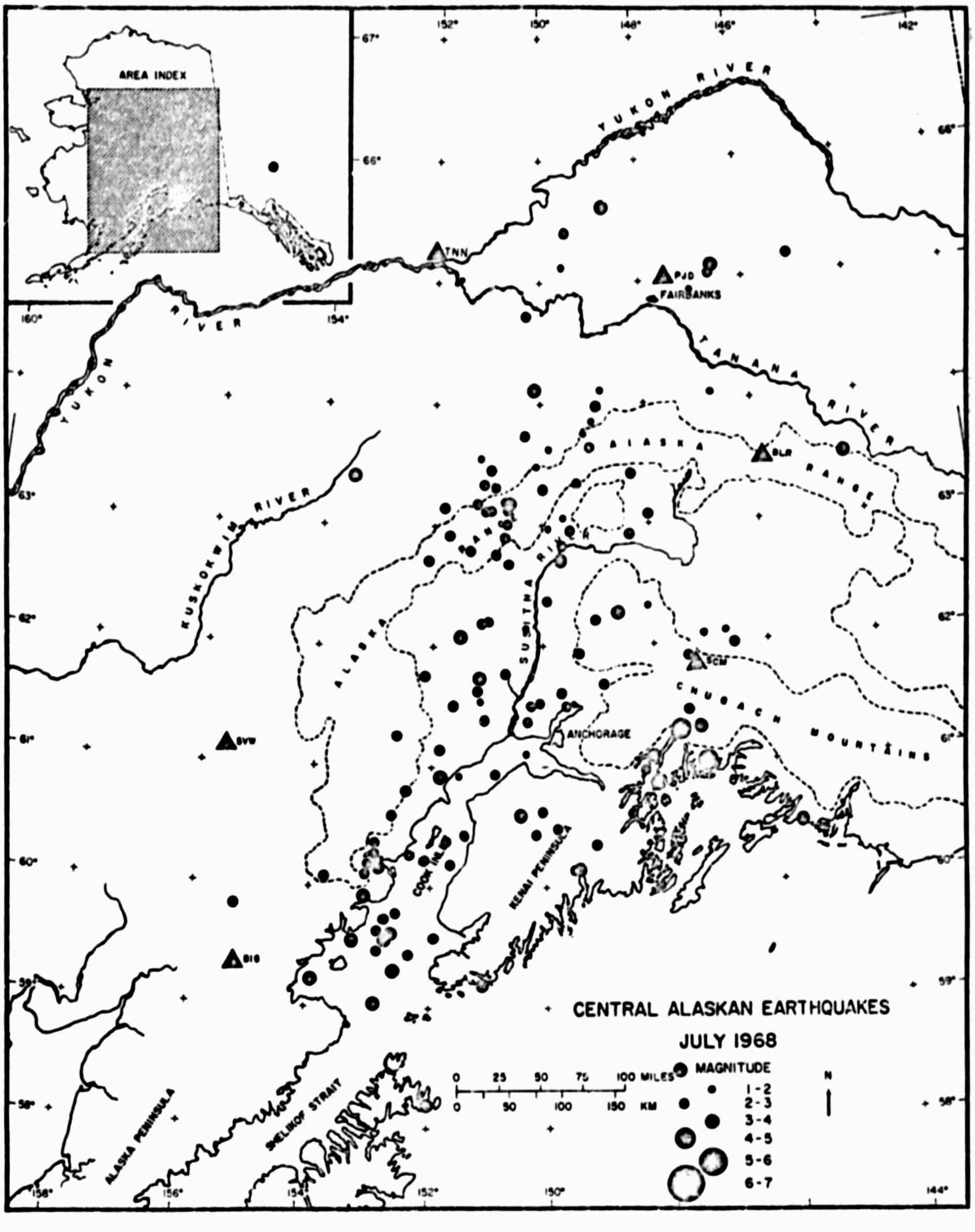
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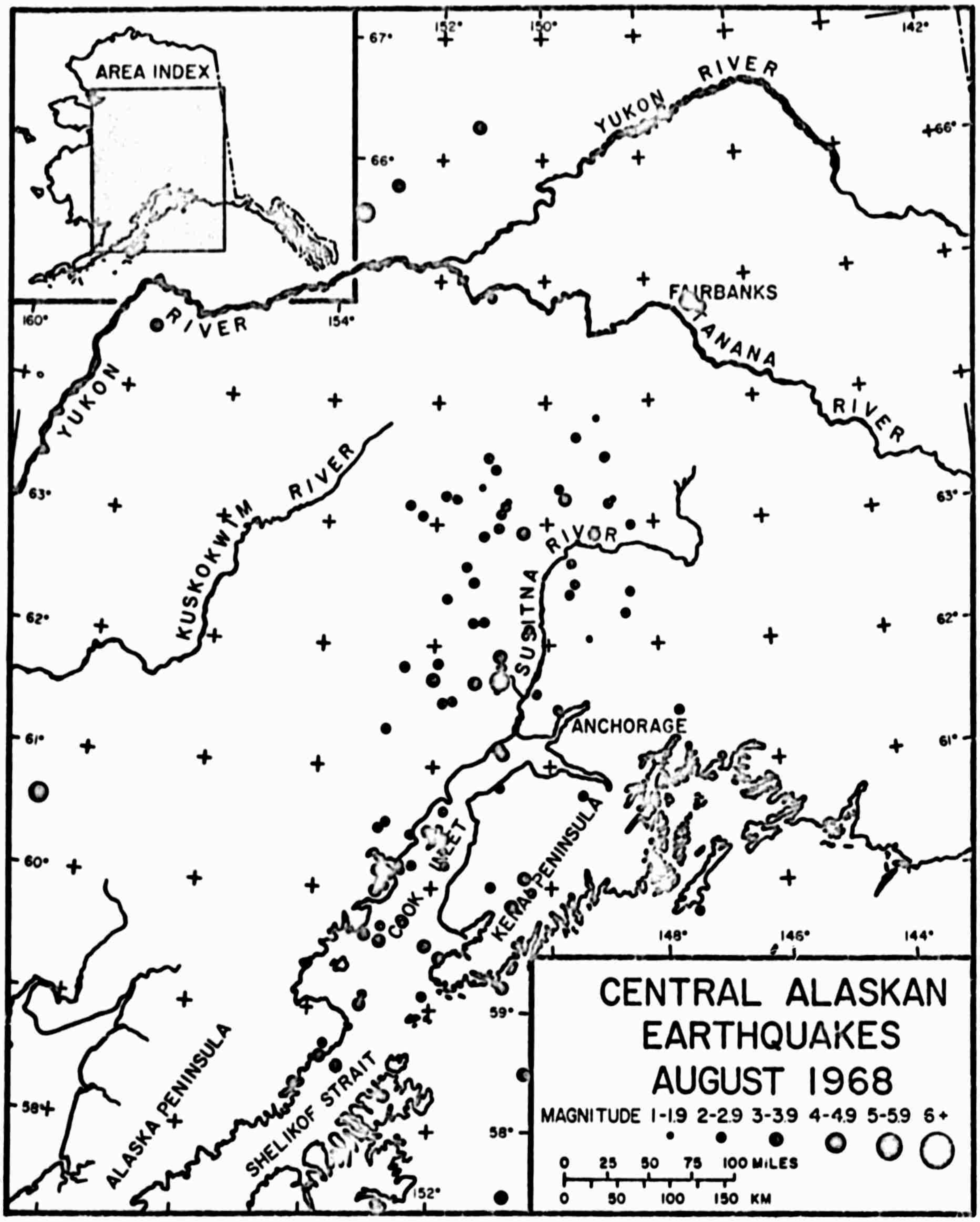
Fig. 2. H.



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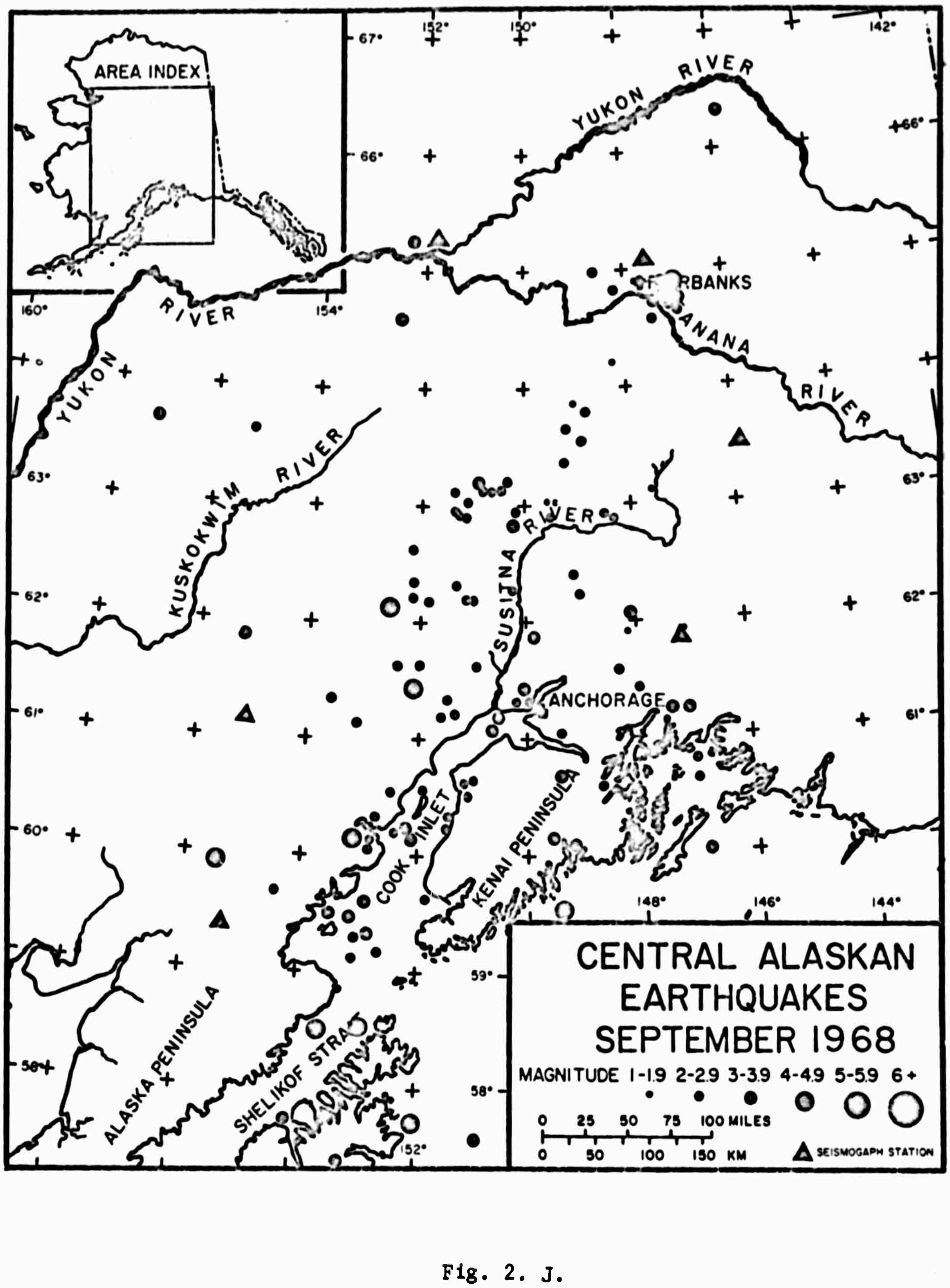
0 50 100 150 KM

Fig. 2. I.



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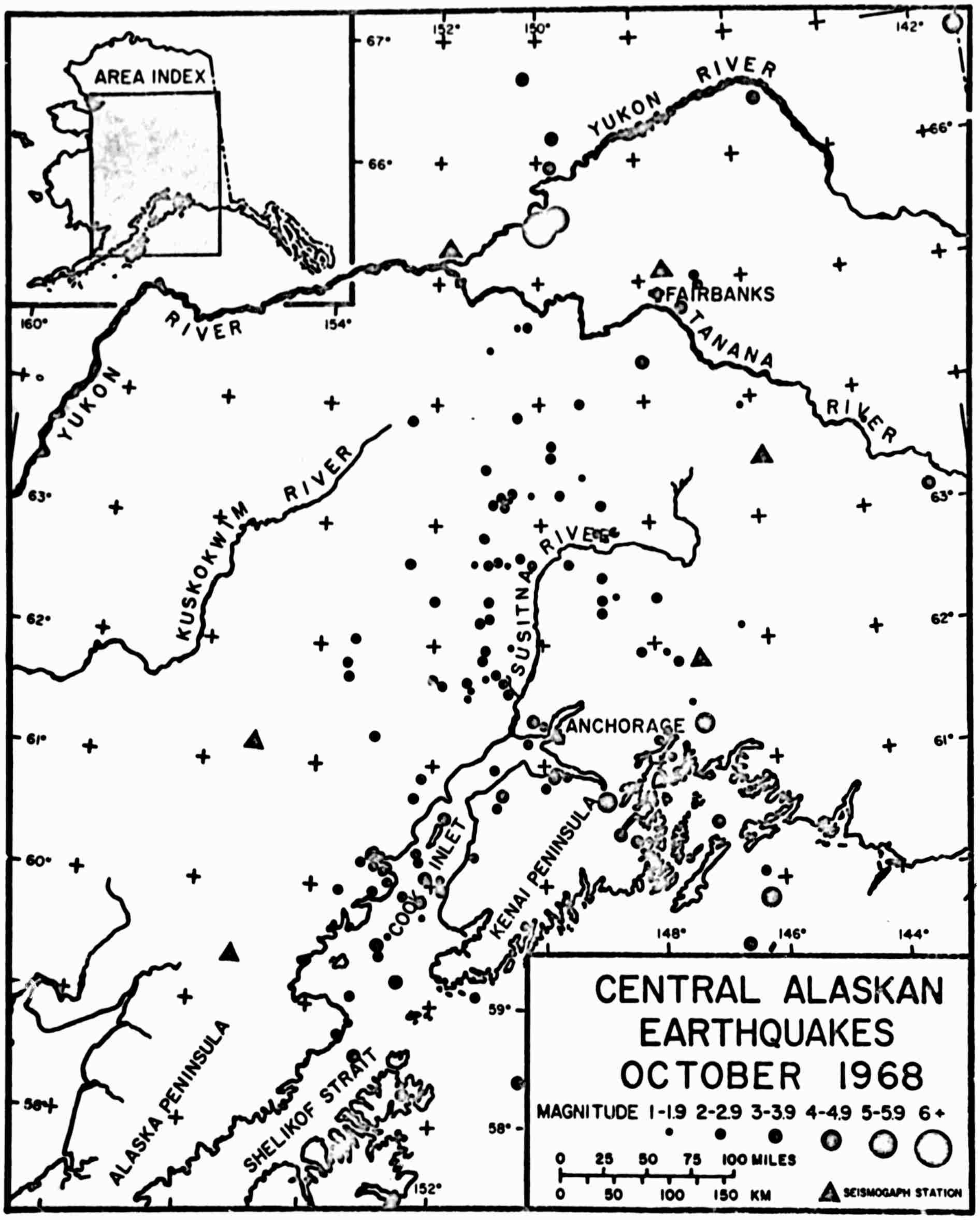
SEISMOGAPH STATION

Fig. 2. J.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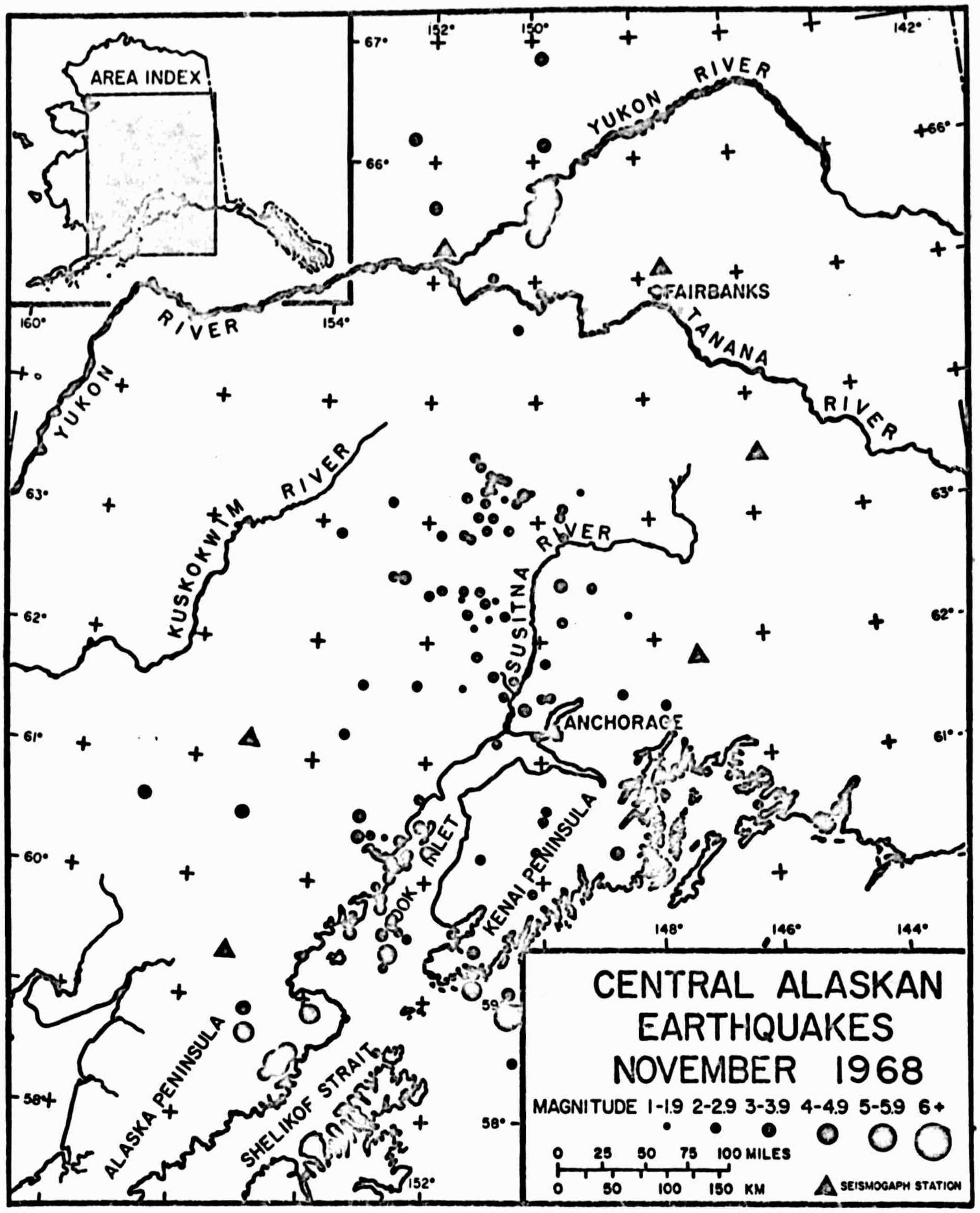
SEISMOGAPH STATION

Fig. 2. K.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SEISMOGAPH STATION

Fig. 2. L.

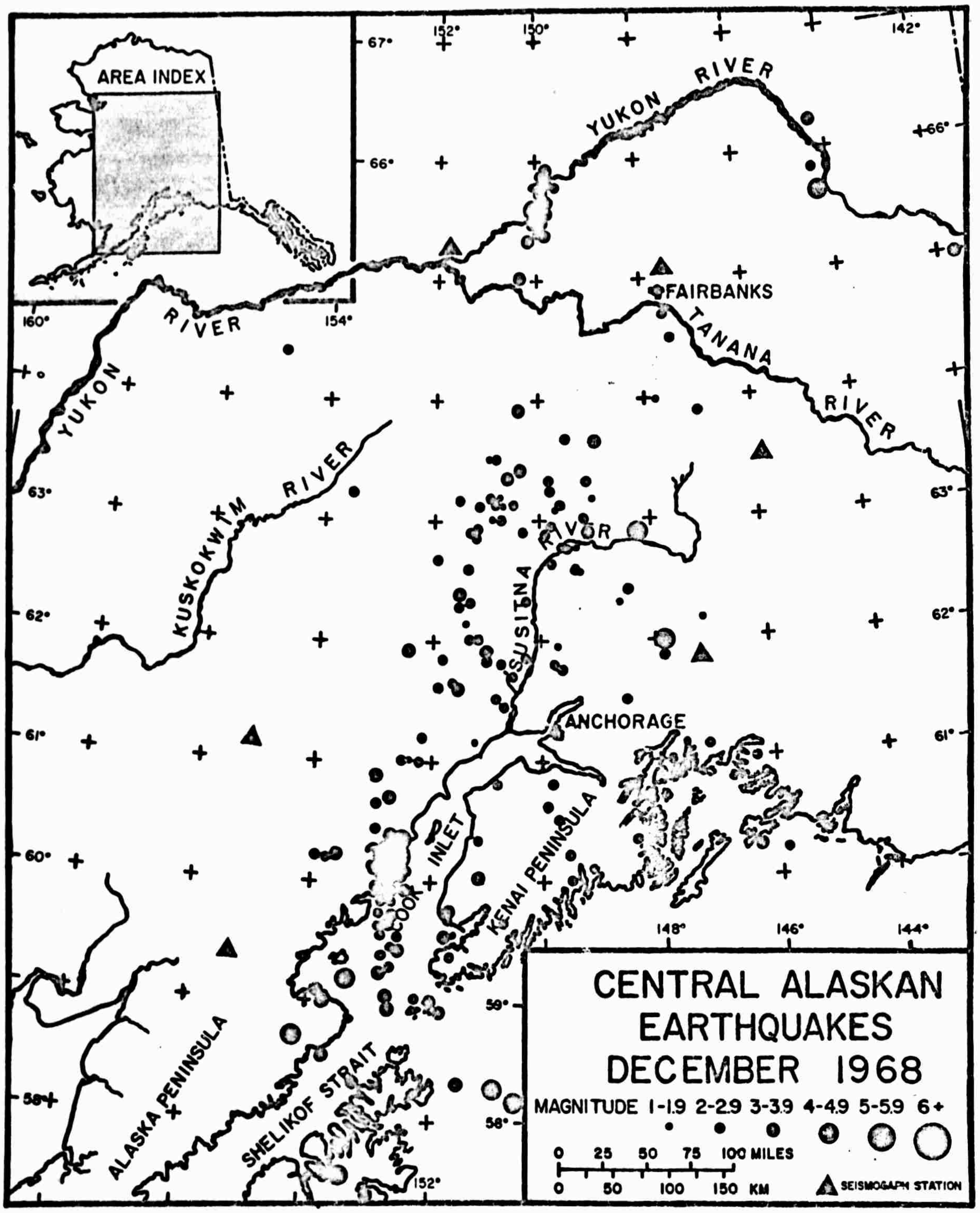
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Fig. 2. M.

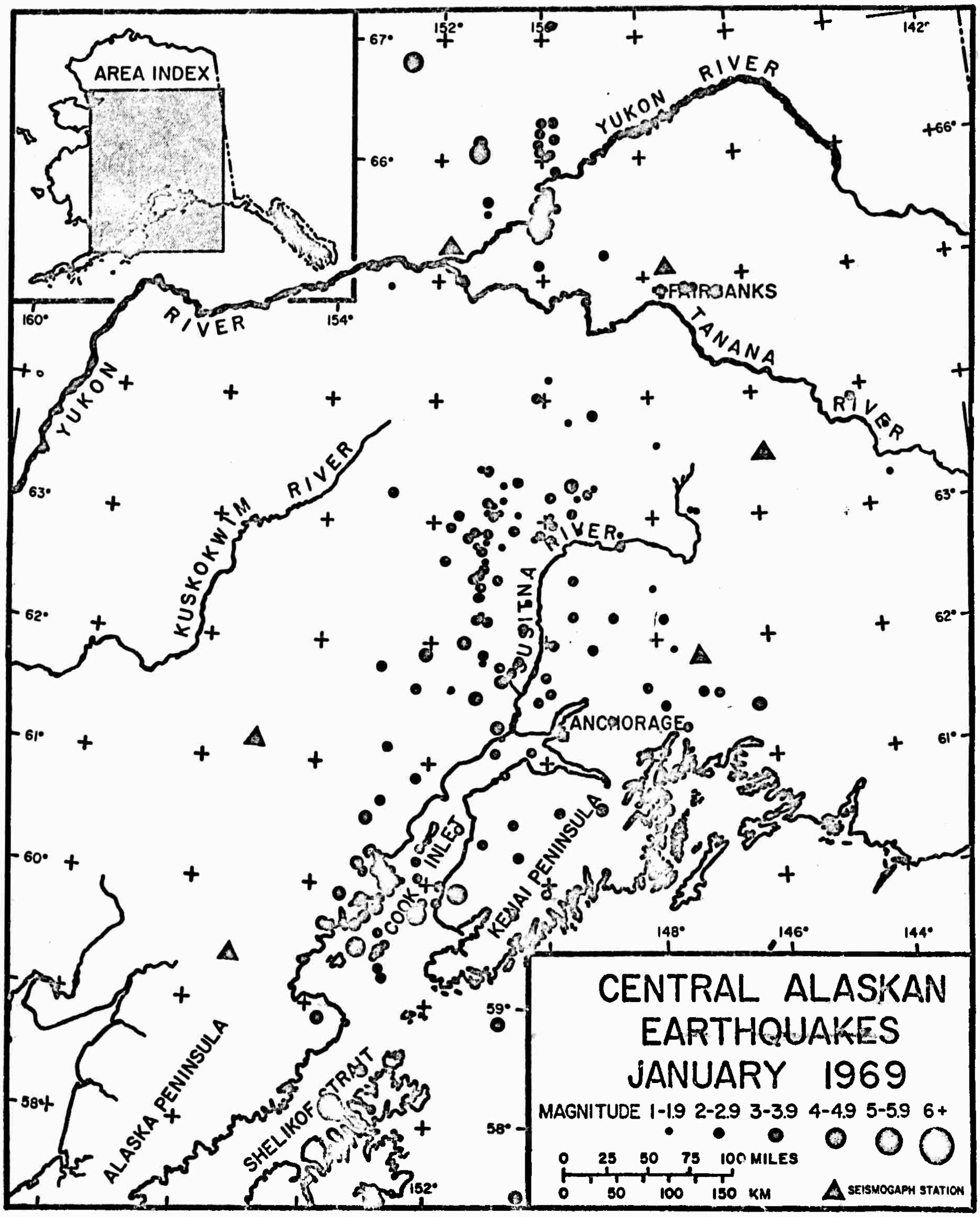
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Fig. 2. N.

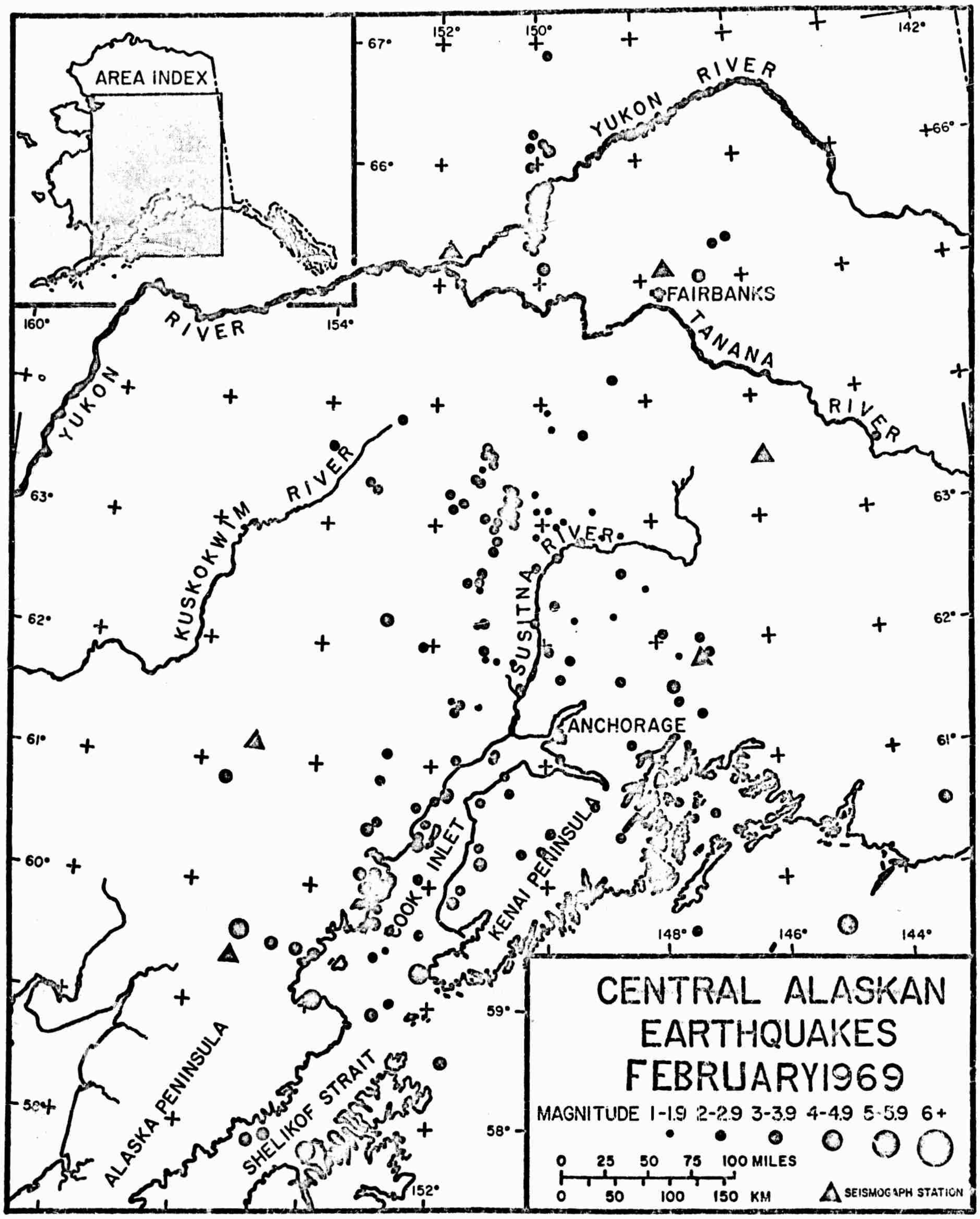

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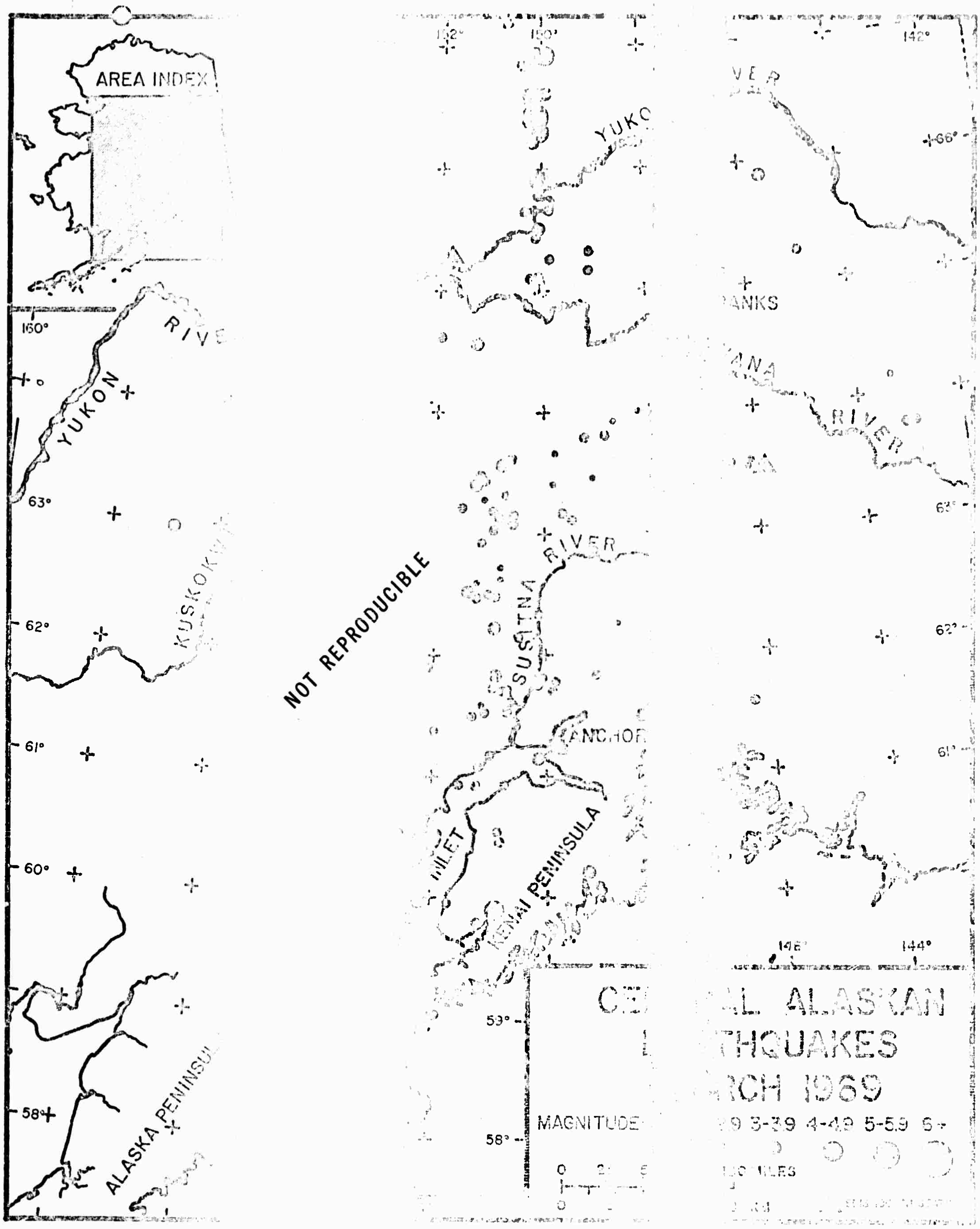
Fig. 2. 0.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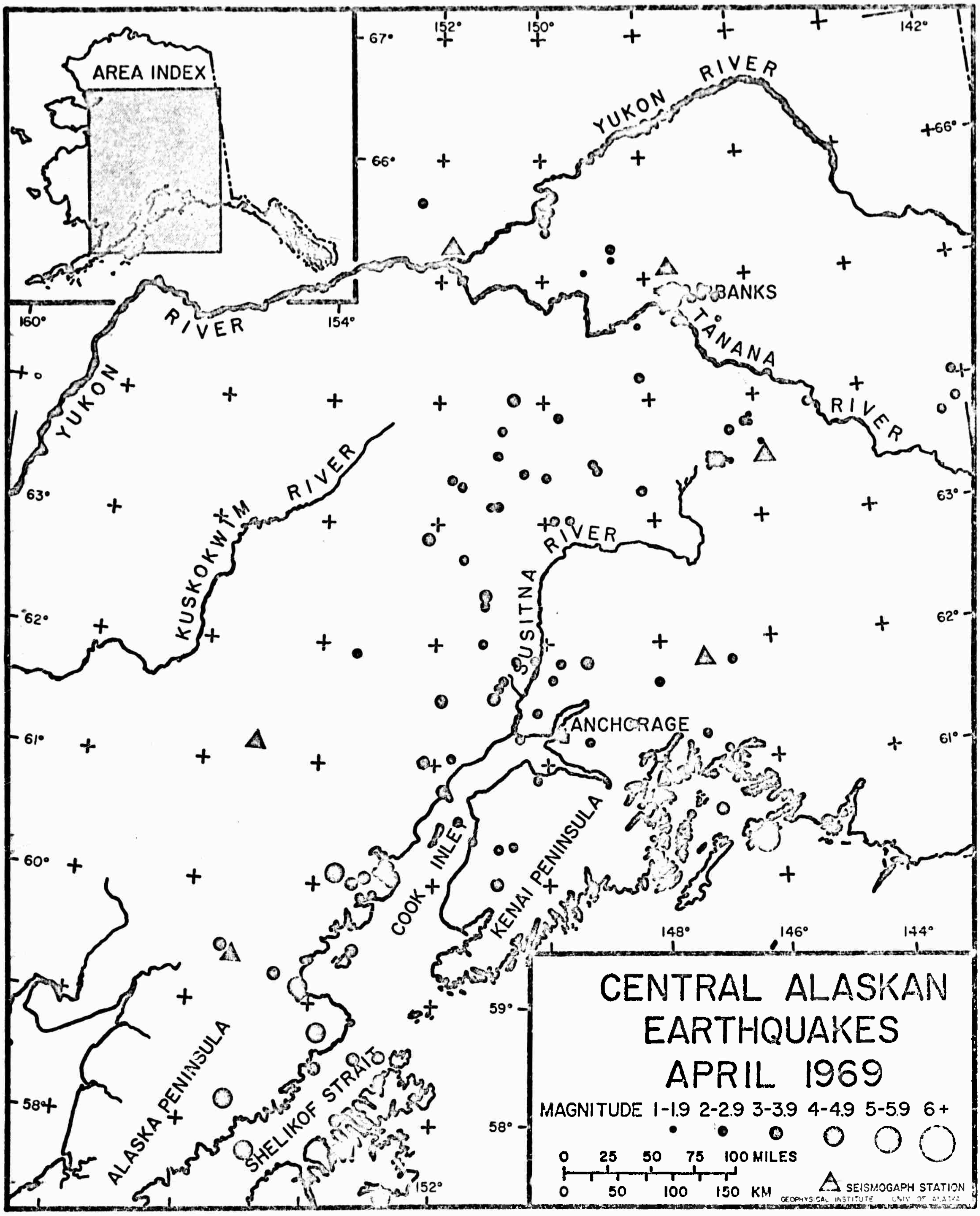
ALASKA PENINSULA
NOT REPRODUCIBLE
SUSITNA
RIVER
ANCHOR
INLET
KENAI PENINSULA
ANKS
RIVER
160°
63°
62°
61°
60°
58°
59°
152°
150°
142°
66°
146°
144°
EARTHQUAKES
MAGNITUDE
3-3.9 4-4.9 5-5.9 6+

Fig. 2. 1.



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CENTRAL ALASKAN
EARTHQUAKES
APRIL 1969
MAGNITUDE 1-1.9 2-2.9 3-3.9 4-4.9 5-5.9 6+
0 25 50 75 100 MILES
0 50 100 150 KM
SEISMOGAPH STATION
YUKON RIVER
RIVER
YUKON
KUSKOKWIM RIVER
TANANA RIVER
SUSITNA RIVER
ANCHORAGE
BANKS
COOK INLET
KENAI PENINSULA
ALASKA PENINSULA
SHELIKOF STRAIT
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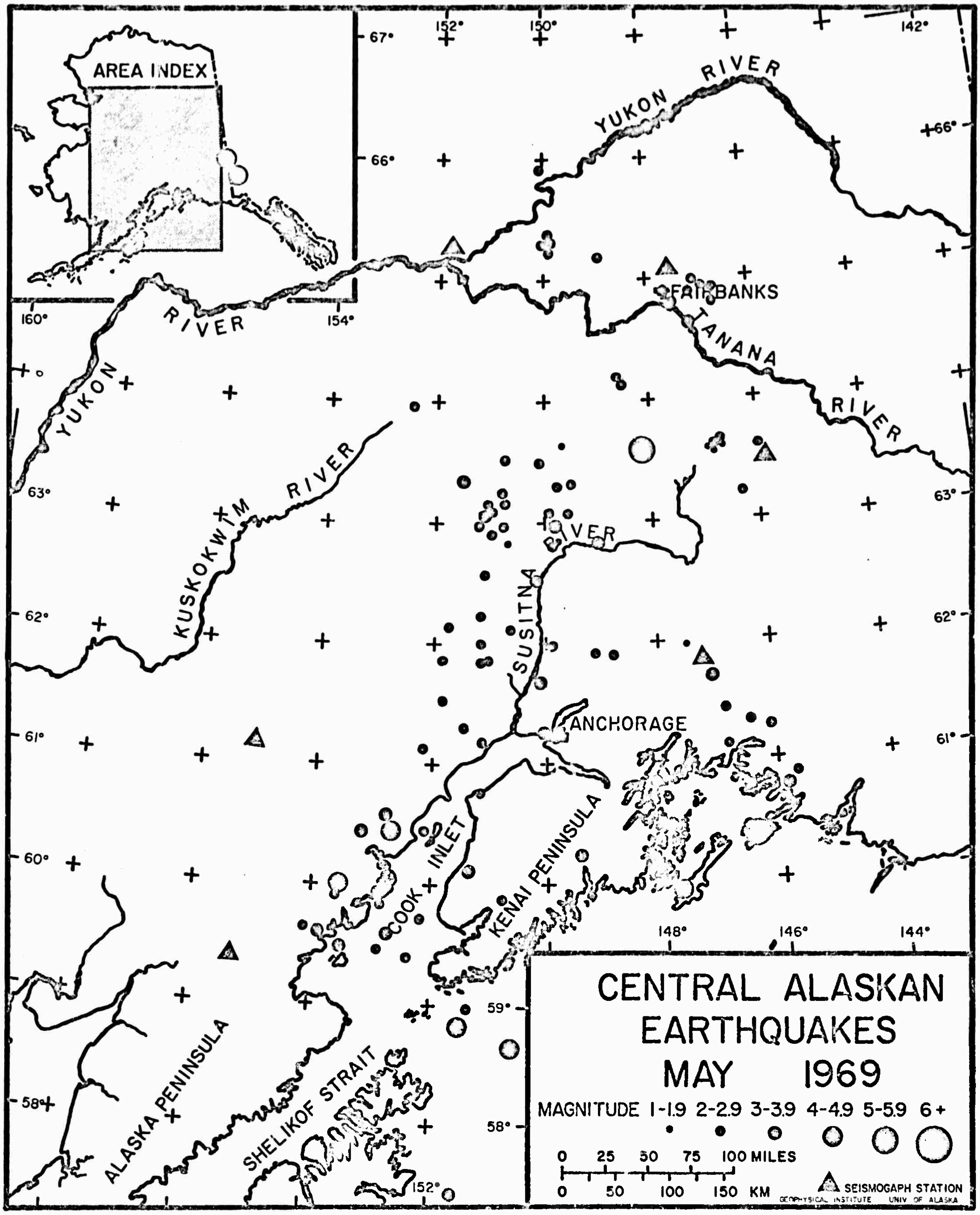
Fig. 2. Q.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0 50 100 150 KM
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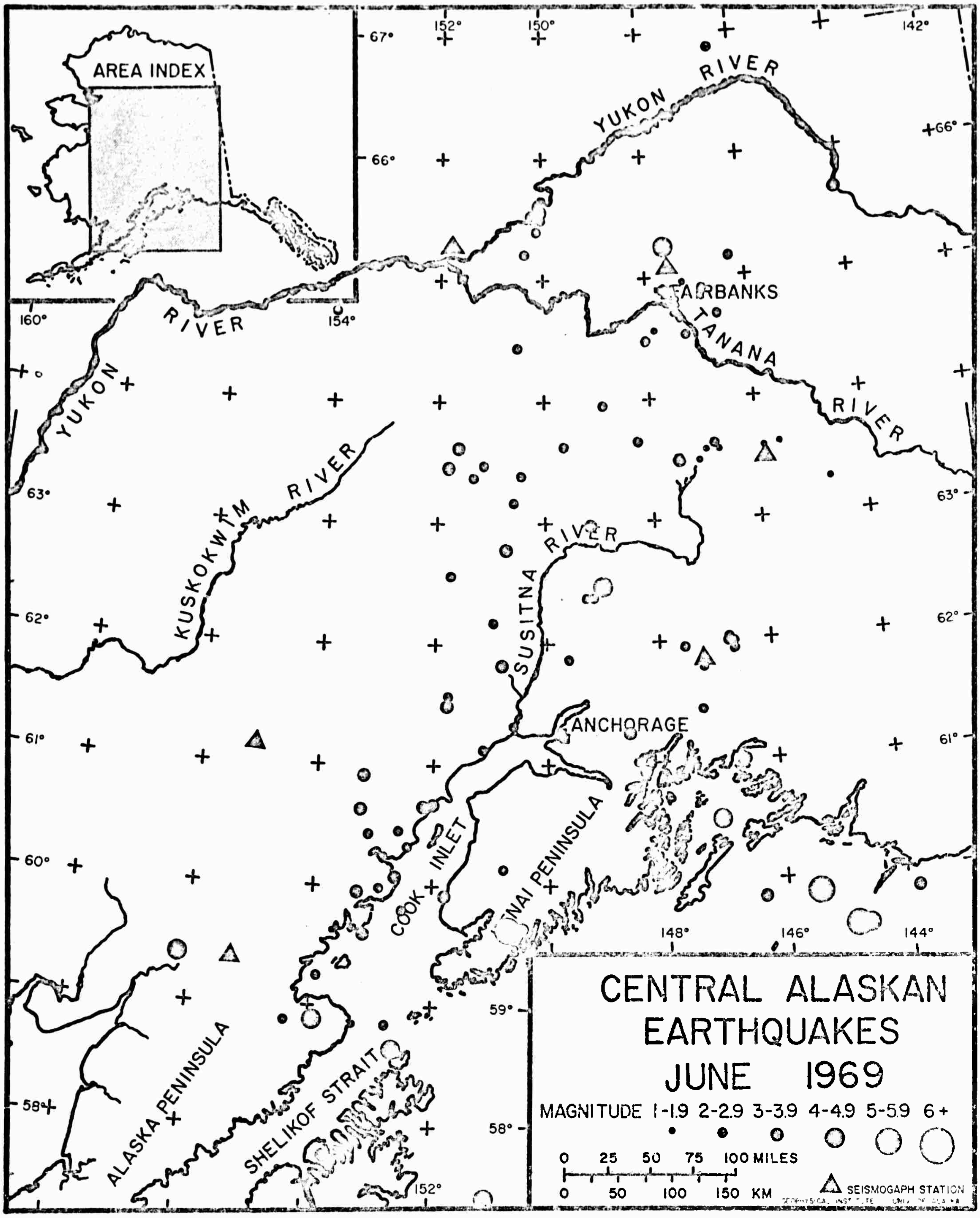
Fig. 2. R.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0 50 100 150 KM
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Fig. 2. S.

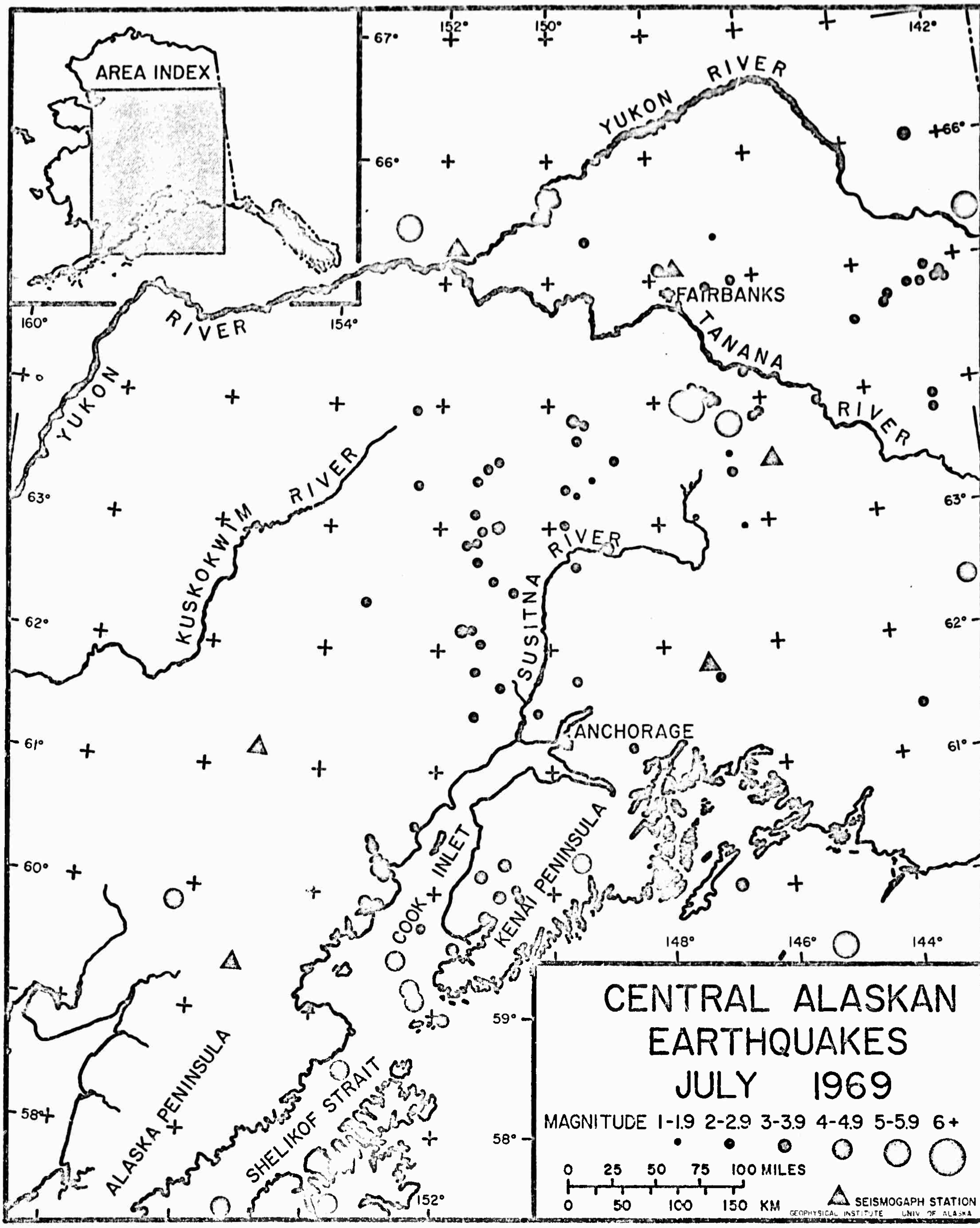
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Fig. 2. T.

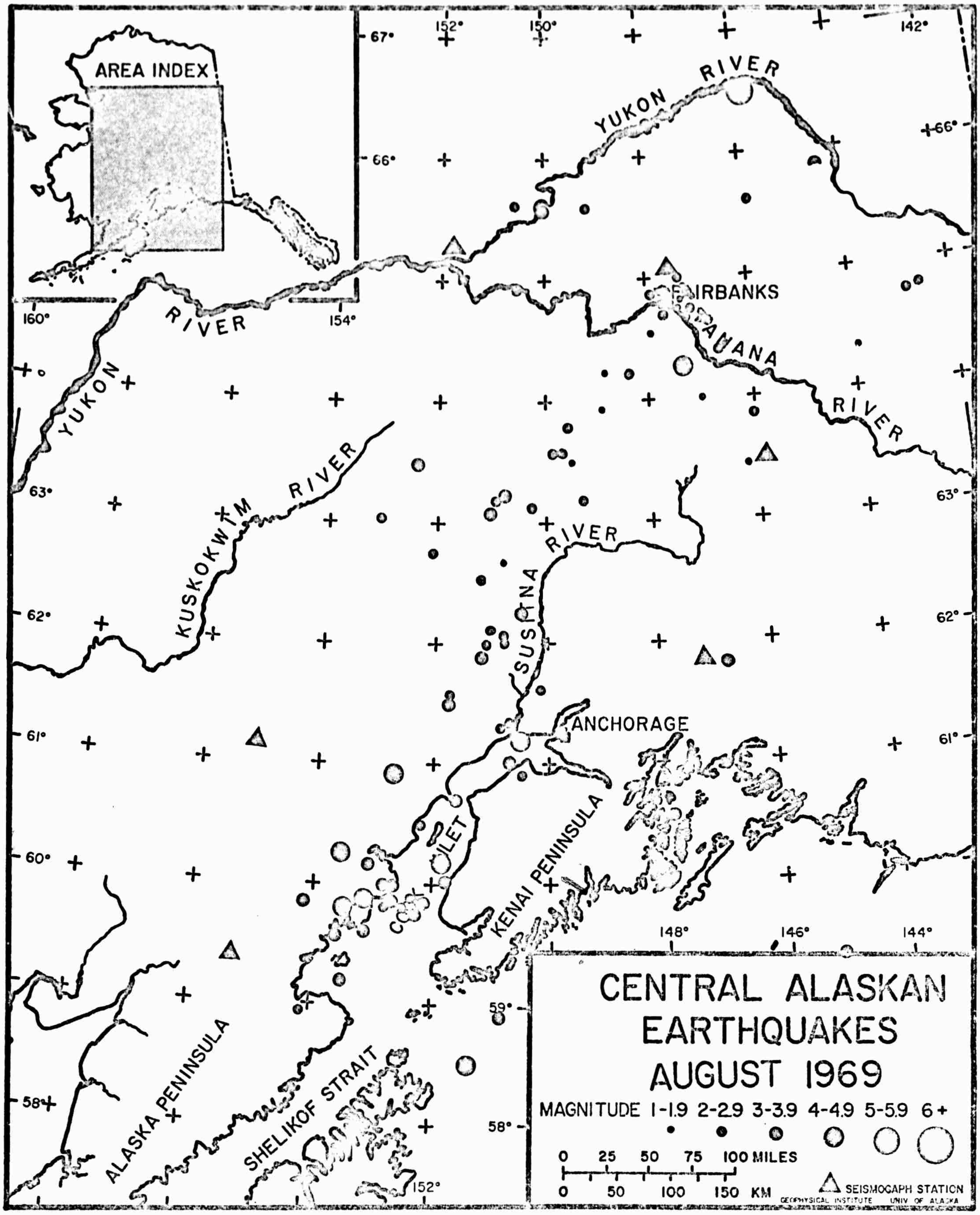

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Fig. 2. U.

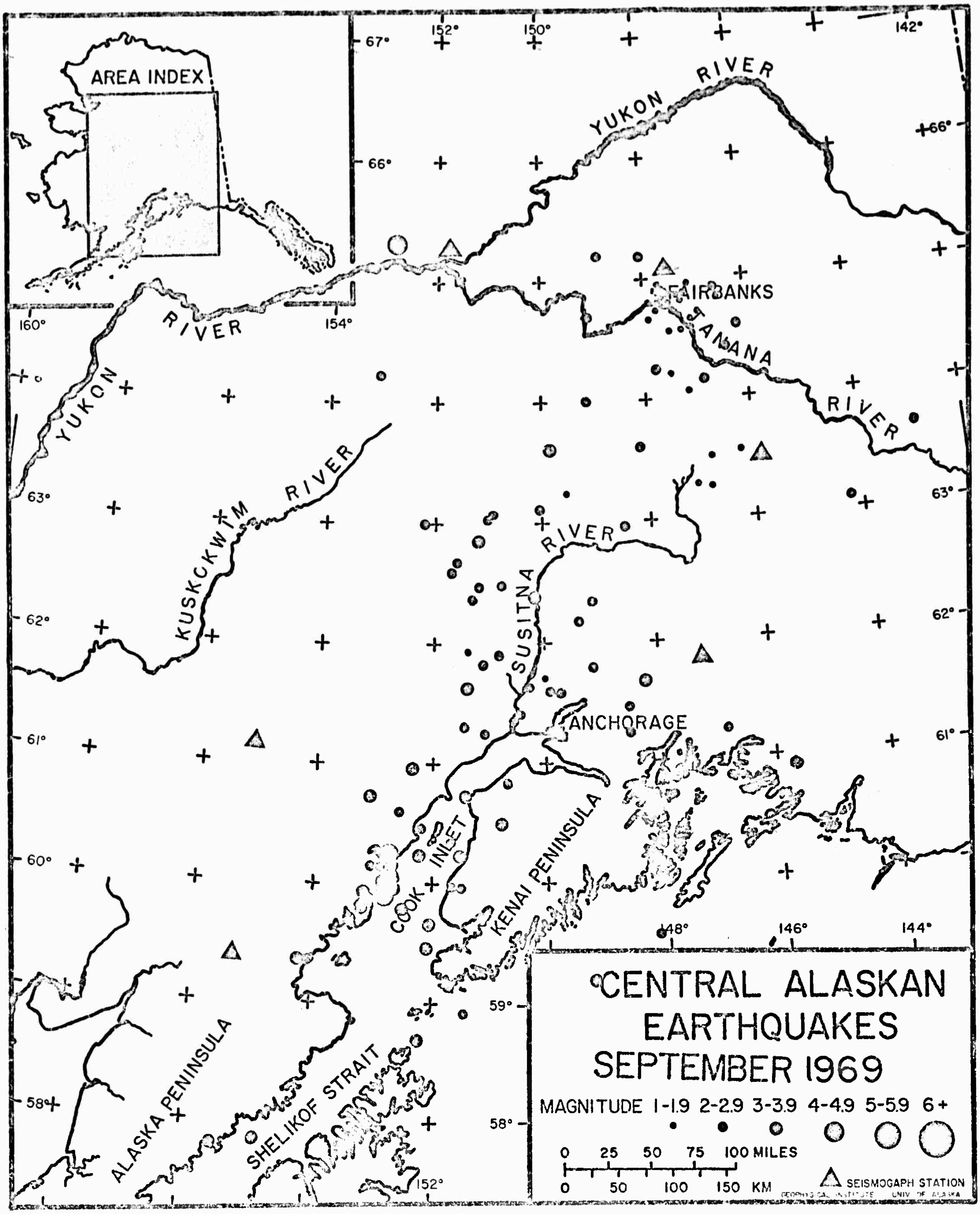
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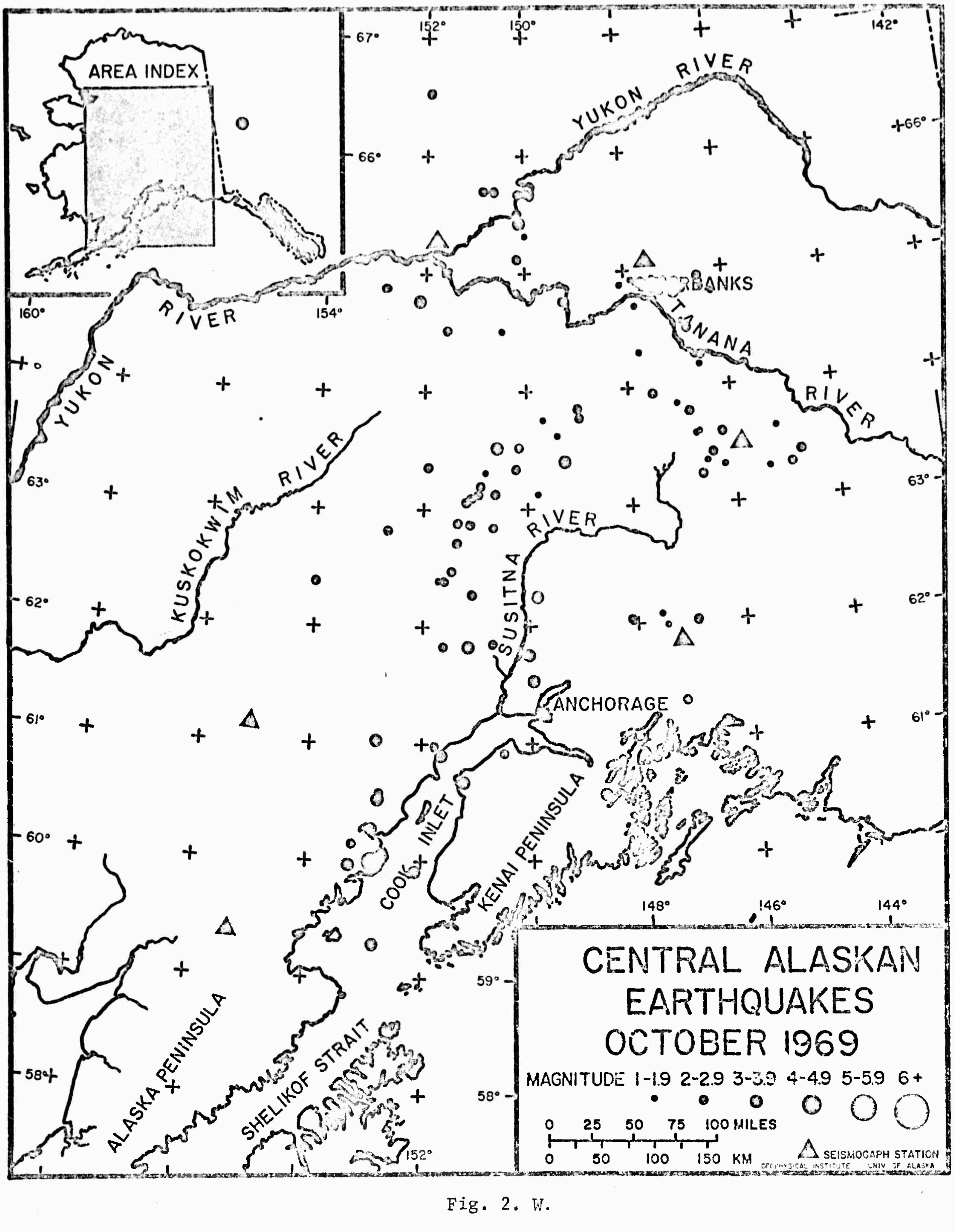
Fig. 2. V.



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MAGNITUDE 1-1.9 2-2.9 3-3.9 4-4.9 5-5.9 6+
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0 50 100 150 KM
SEISMOGRAPH STATION

Fig. 2. W.

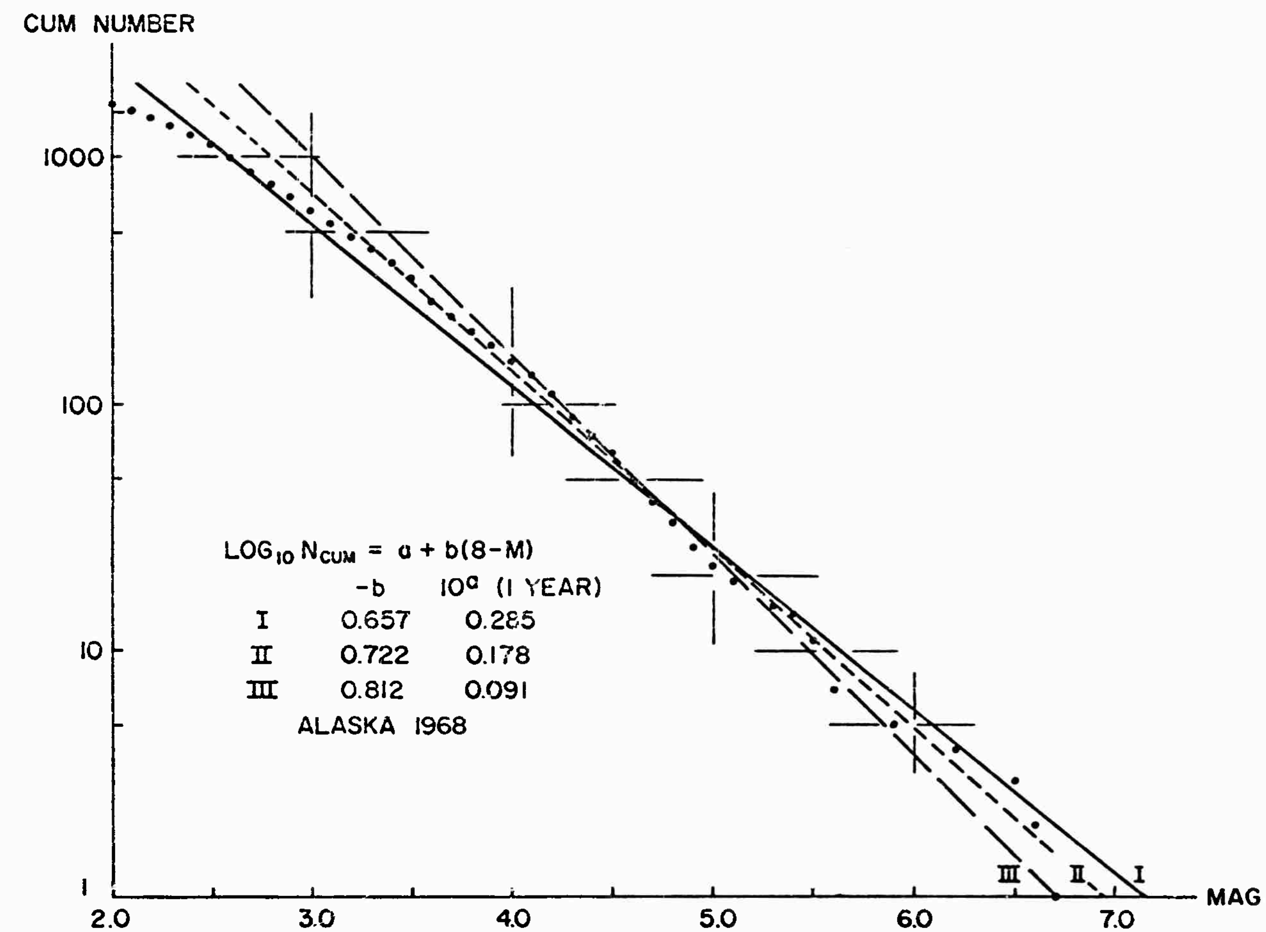


Fig. 3. Earthquake Recurrence Rate for Central Alaska 1968.

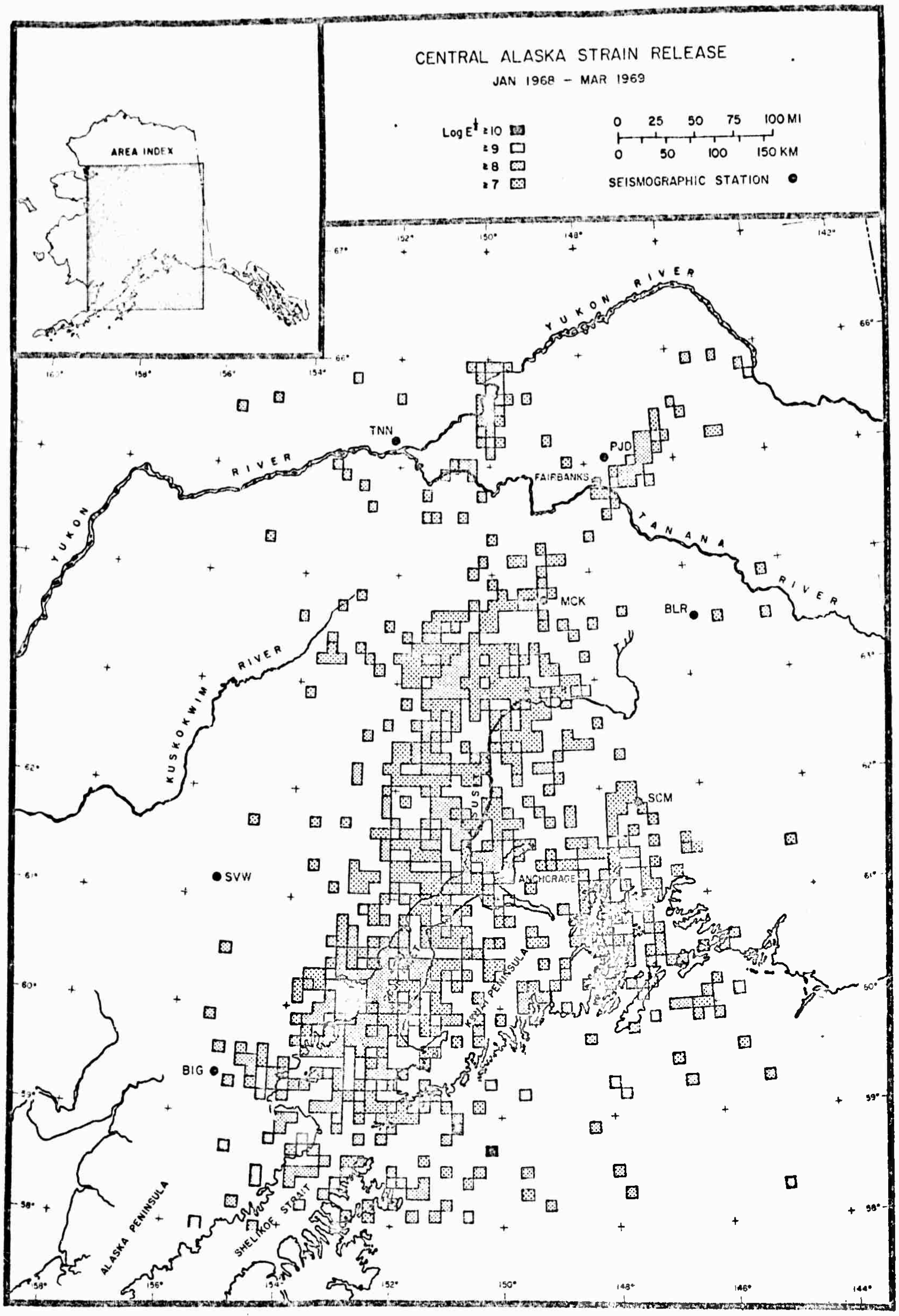


Fig. 4. Strain Release Map for Central Alaska.

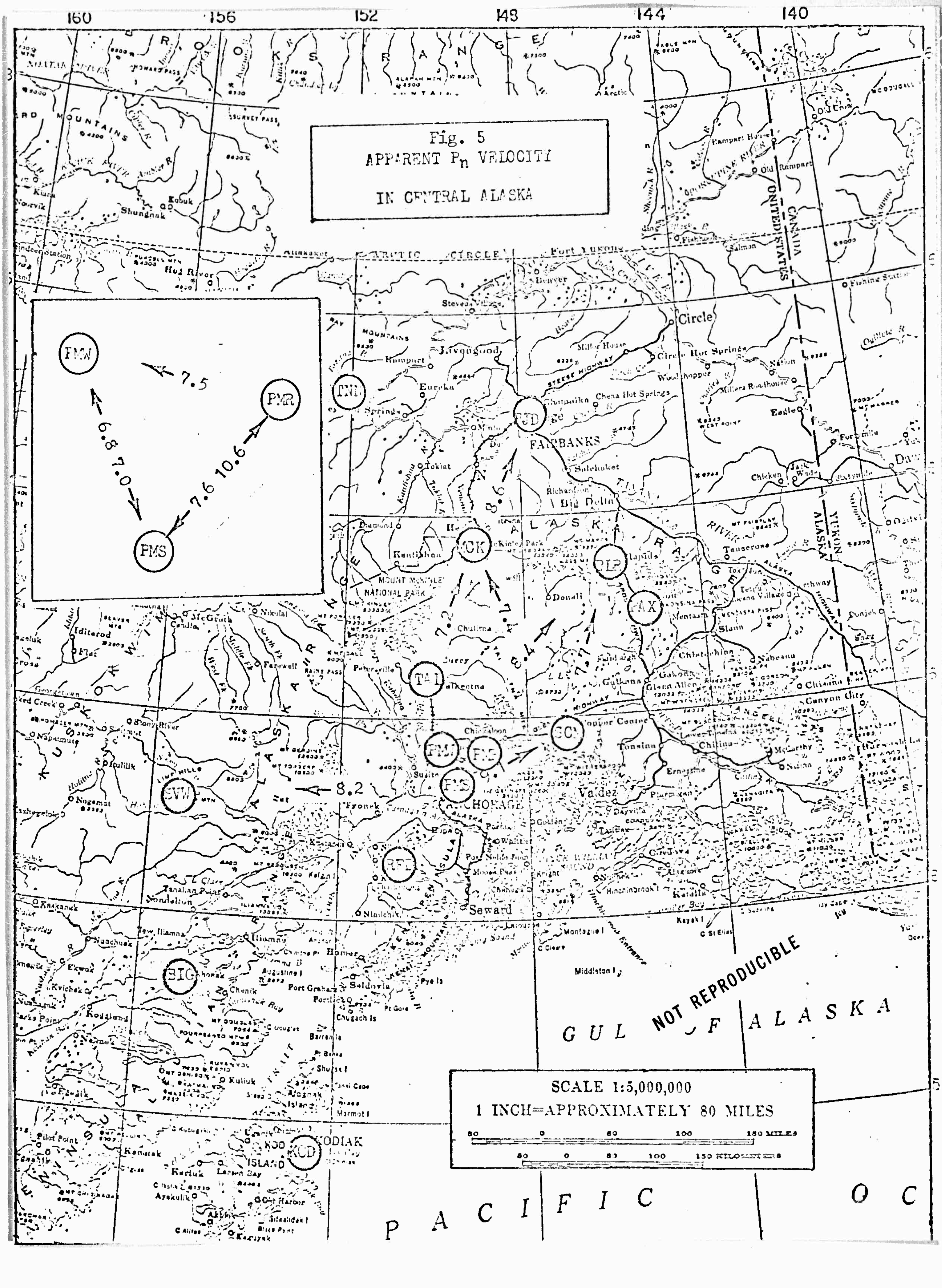


Fig. 5
APPARENT P_n VELOCITY
IN CENTRAL ALASKA

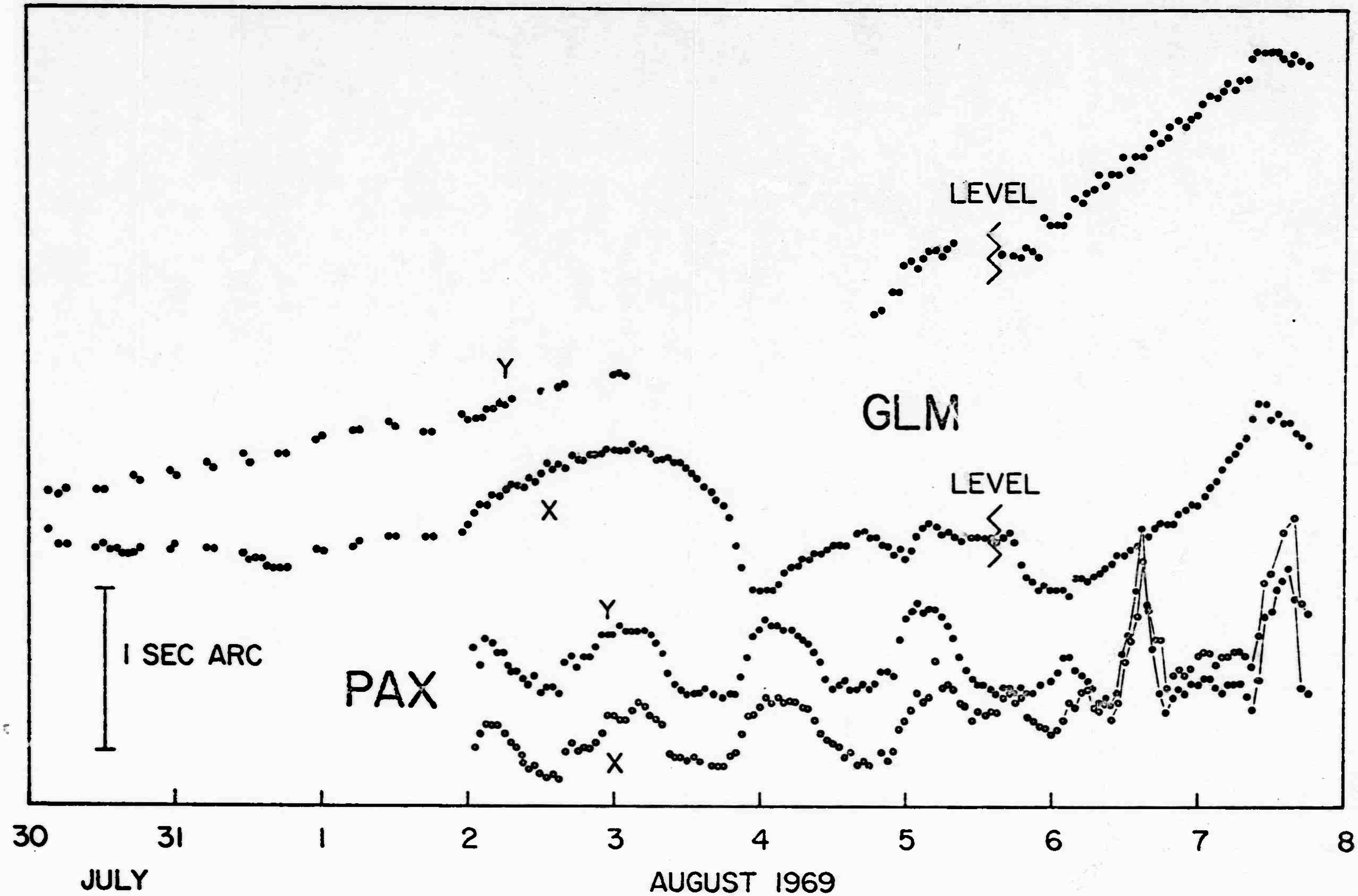


Fig. 6. Tilts for GLM and PAX, 30 July through 8 August, 1968; for Explanation see text.

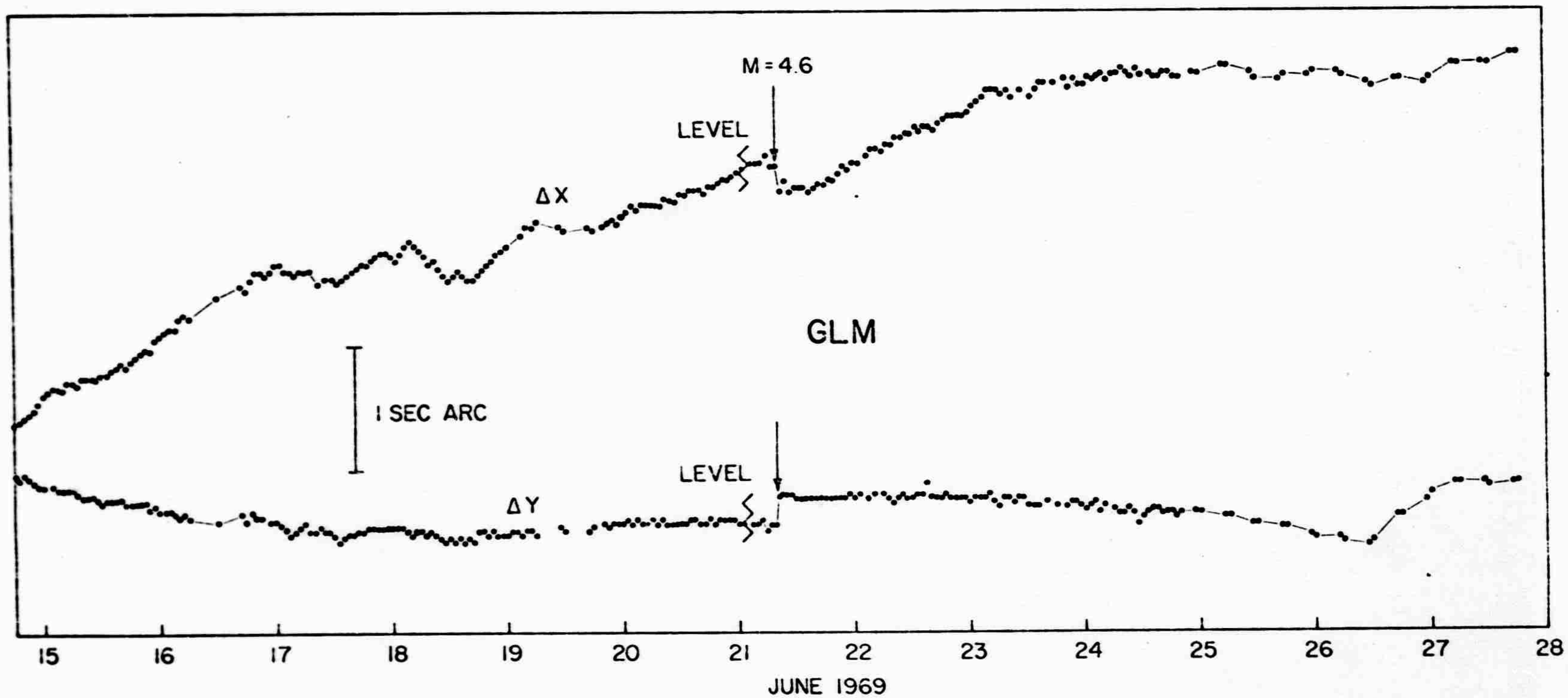


Fig. 7. Tilts for GLM 15 through 27 June 1969.

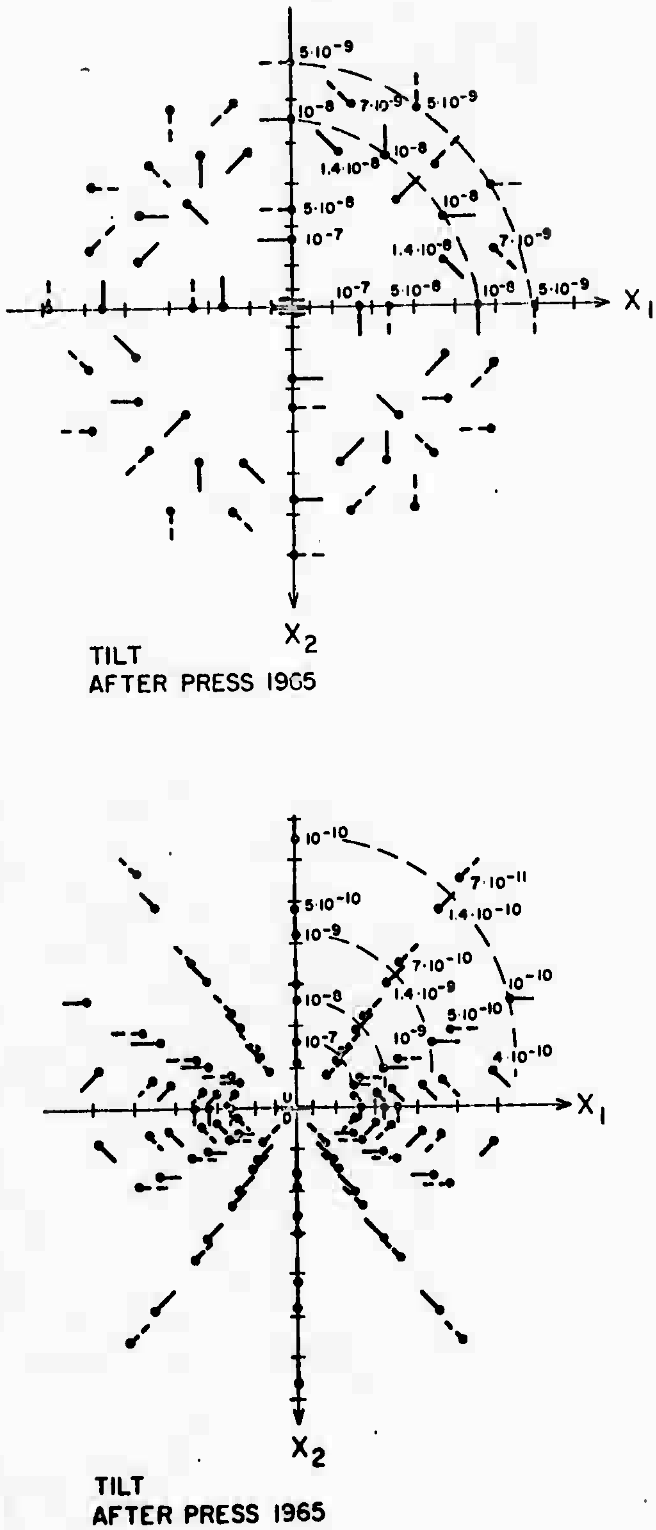


Fig. 8. Tilt Fields for Strike and Dip Slip Fault (using calculations from Press, see text).

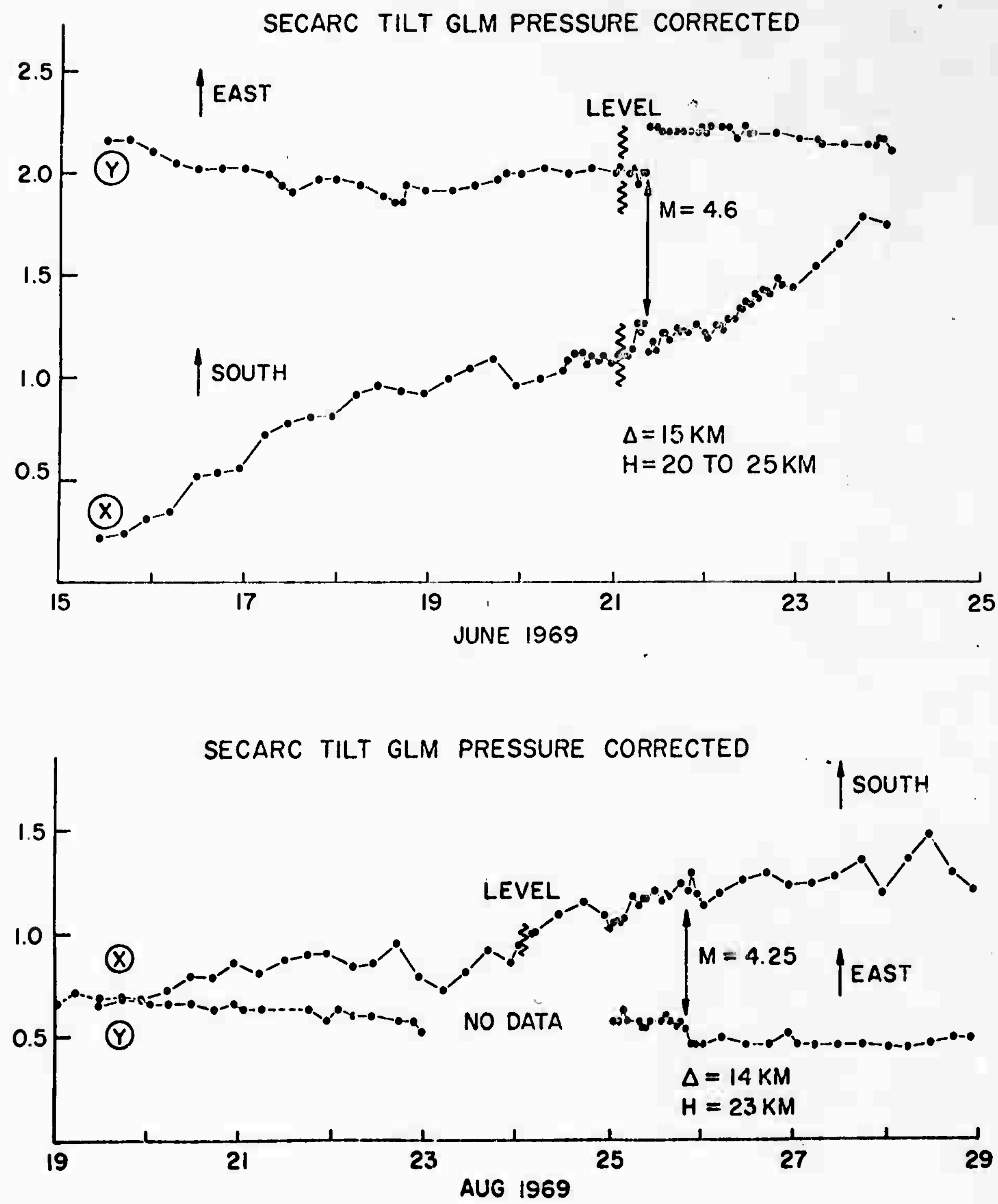


Fig. 9. Tilts 15 through 25 June 1969 and 19-29 August 1969, Pressure Corrected by Calculation.

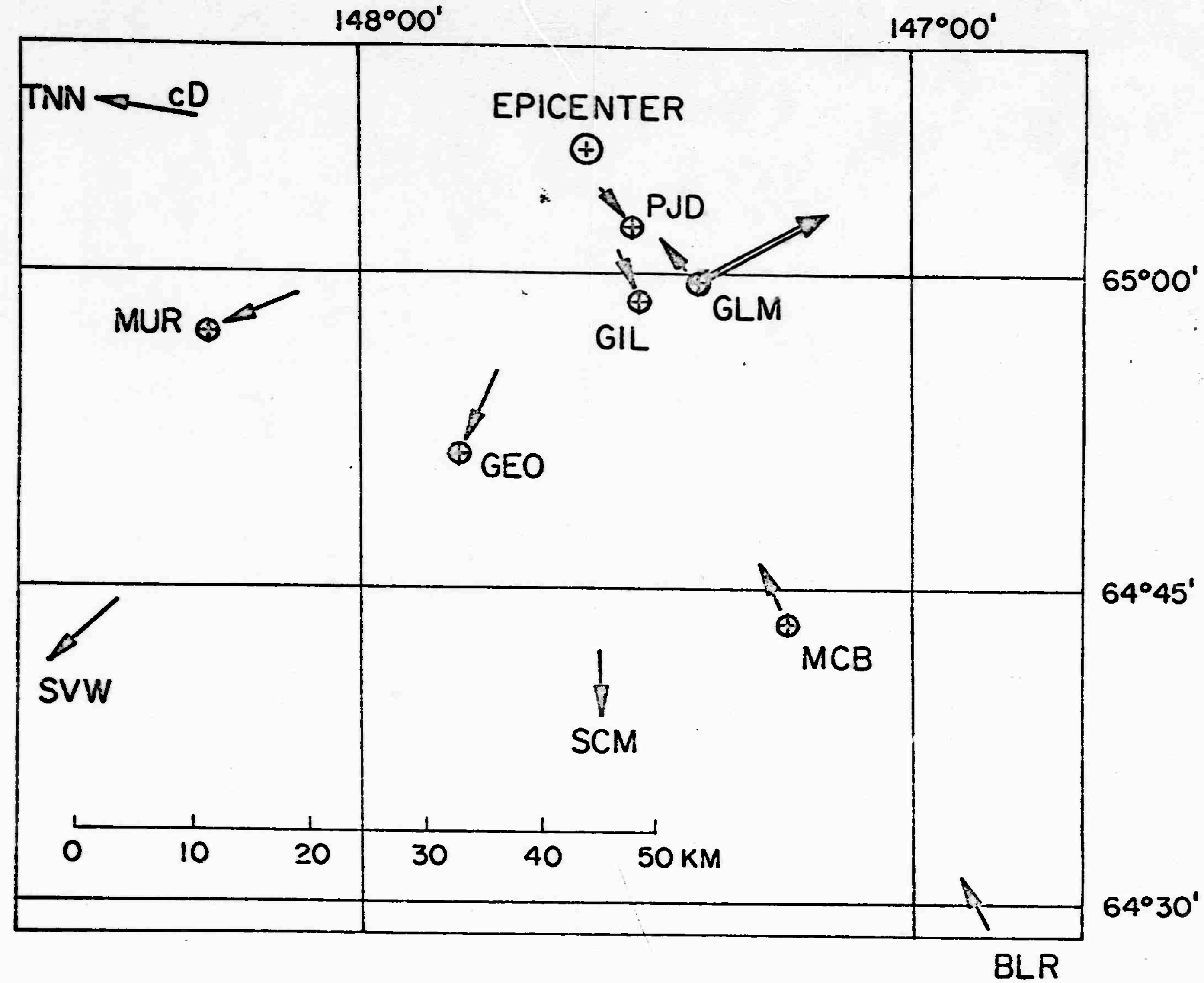
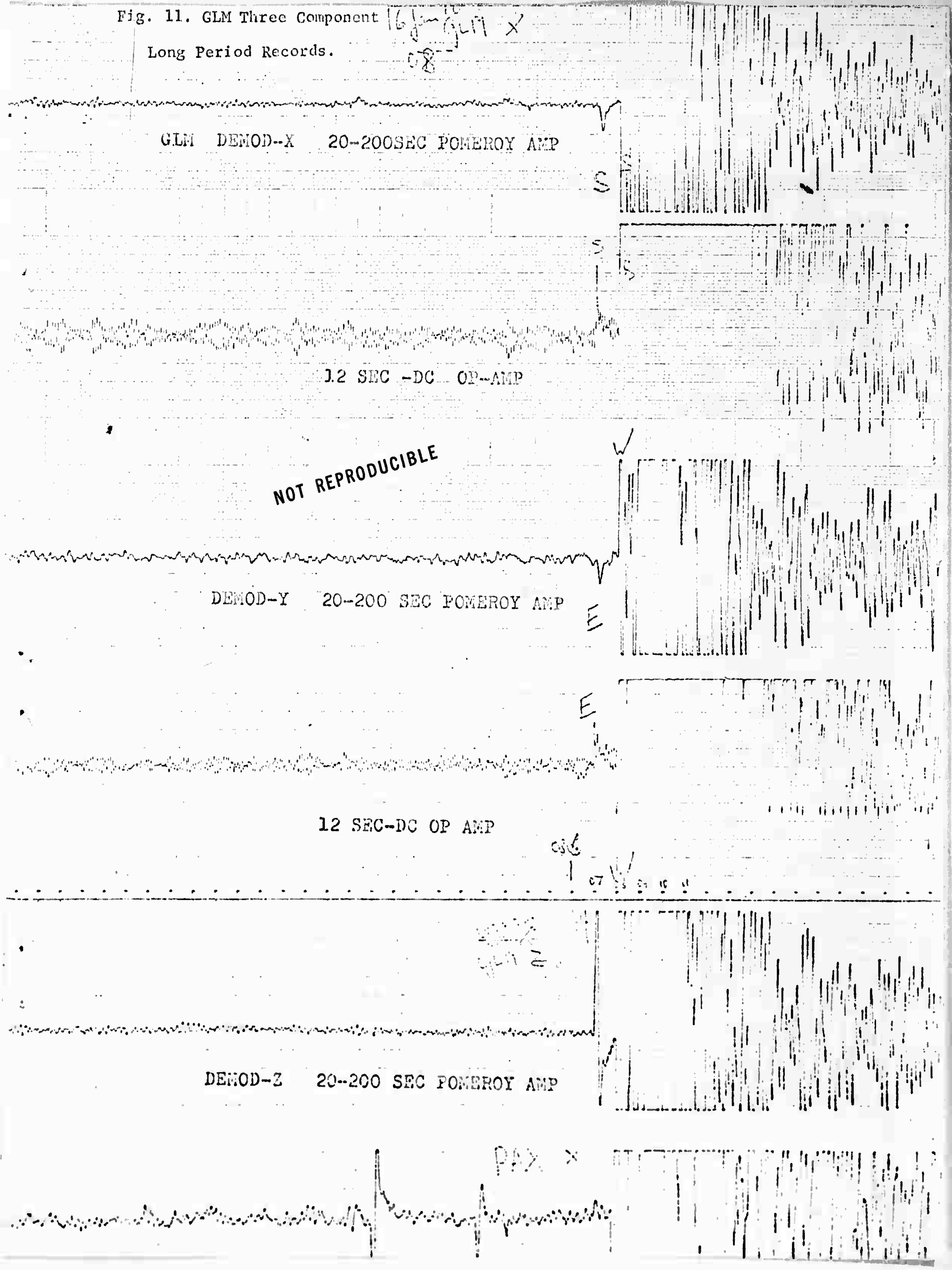


Fig. 10. June 21, 1969 Fairbanks Quake, First Motion and Tilt Direction.

Fig. 11. GLM Three Component Long Period Records.



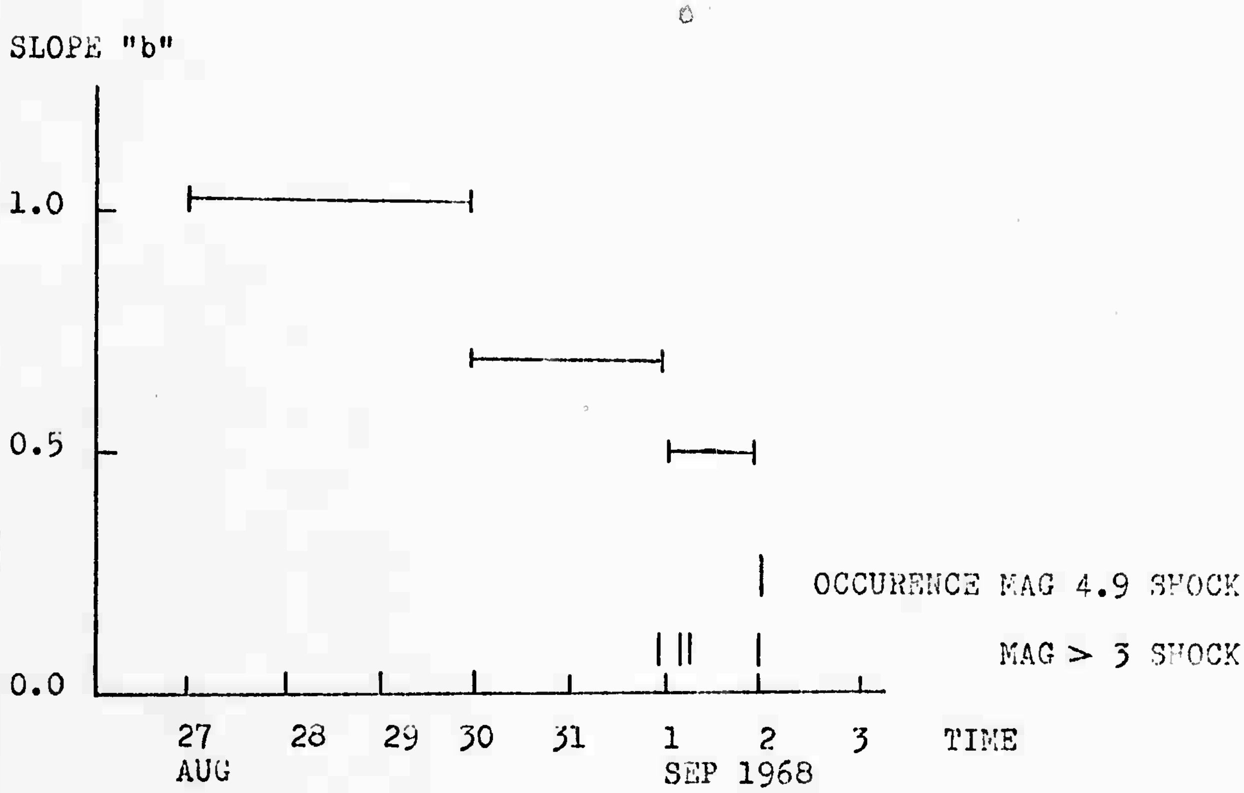


Fig. 12. Time Variation of Slope "b" in the Fairbanks Aftershock Zone. Numbers next to Slope Values Indicate Sample Size.

Unclassified

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13. ABSTRACT

The seismic telemeter system data now cover a total of three years record for central Alaska. Monthly epicenter maps for the contract period are given. The tectonic pressure axis have been determined using earthquakes occurring in the network. Three borehole packages of the USO type have been installed in Gilmore, Paxson and McKinley. It was found that the construction of the long-period part of the borehole package makes the LP-X component a very sensitive microbarograph, covering the period range from 15 sec to DC. Tilts associated with local earthquakes of small magnitude at short distances are discussed.

Laboratory results on brittle rock failure seem to be valid for the earth crust. If foreshocks occur at all, the "b" slope of the Gutenberg-Richter Relation, linking the log of the number to the magnitude of the earthquakes, seem to indicate high average stress levels for small areas and prior to a small main shock, the larger areas associated with relatively stronger earthquakes seem to be associated with lower average stress levels. ( )

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Large Aperture Telemeter System, Alaska						
Epicenters, Seismicity, Strain Release						
Tectonic Pressure Axis in Alaska						
Fairbanks Earthquake, June 21, 1967						
Long Period Borehole Seismometers, Tilts						
Crustal Structure Central Alaska						
Foreshocks, Stress, Mainshocks						
Small Earthquake Associated Tilts						

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